THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME VIII NOVEMBER 1898 NUMBER 4

THE PROBABLE RANGE OF TEMPERATURE ON THE MOON. I.[1]

By FRANK W. VERY.

THE subject may be approached from the experimental side in two ways:

The first supposes the radiation from different lunar regions to have been observed at various phases, and the proper radiation of the heated lunar surface to have been distinguished from solar radiation immediately reflected. The observations require further correction for the changes produced by the absorbing action of the Earth's atmosphere upon different rays.

The radiant values thus given will be stated in terms of some arbitrary scale of units. Before the results can be interpreted, the values must be transformed and given in terms of absolute measurement. This involves two steps:

a. The determination of the law connecting radiation and temperature for the measuring instrument and comparison body used in observing the lunar radiation, and the transformation of arbitrary into absolute values for the standard substance.

b. A comparison of the radiant emissivity of the standard substance with that of such materials as may reasonably be assumed to make up the lunar surface, and a fixing of the prob-

[1] Read at the Harvard Conference, Aug. 25, 1898.

able variation of temperature to be anticipated with departure from standard conditions.

The second method of attacking the problem of lunar temperature starts with the solar radiant constant, as determined by observations corrected for atmospheric absorption, and assuming such laws of reflection and absorption of solar rays, and such retention of heat and powers of emission in the lunar surface as are indicated by observation, proceeds to trace the consequences as far as these affect the diurnal range of temperature on the Moon.

The law connecting radiation and temperature will form the subject of a special paper, but the general results are given in Table B (Part II).

The first part of the present article describes the author's measurements of emissivity for several substances at moderate temperatures.

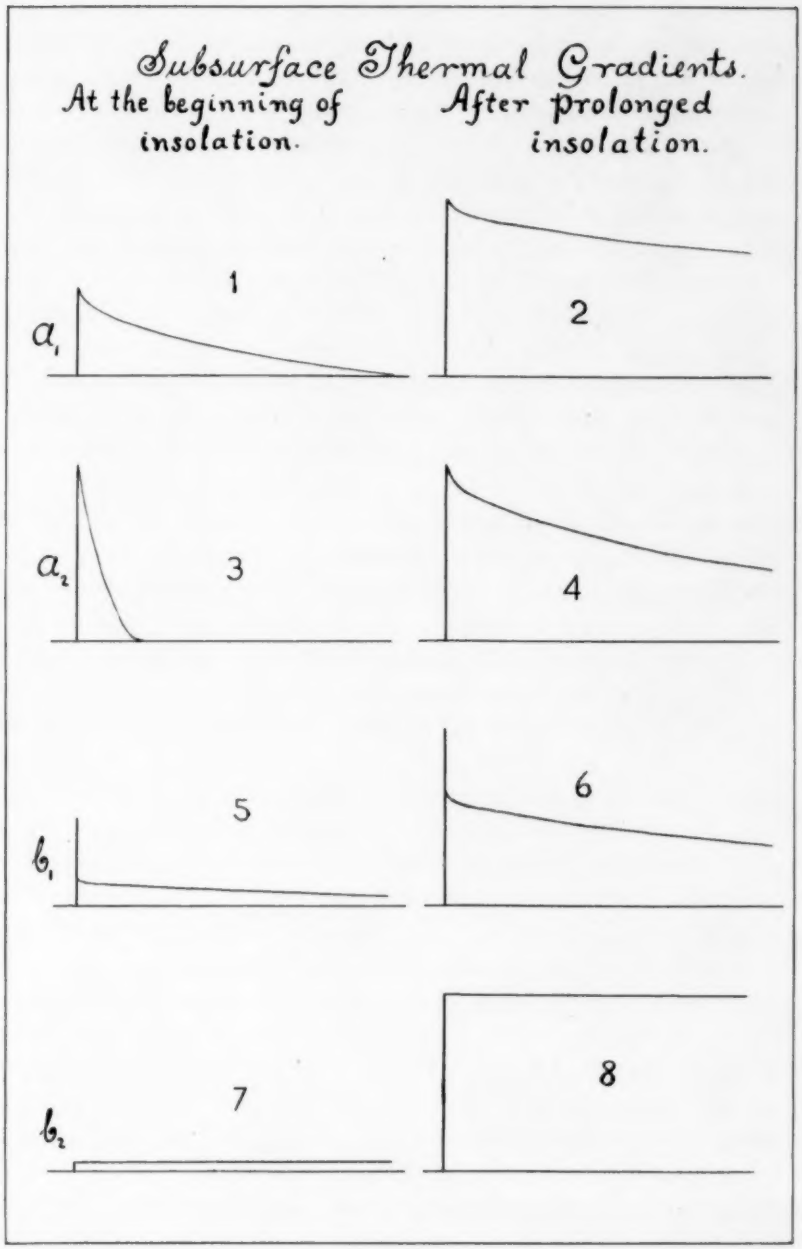
Radiators may be divided somewhat arbitrarily into the following classes :

(a) Good surface radiators which are
  (a_1) good conductors of heat,
  (a_2) bad conductors of heat.
(b) Bad surface radiators which are
  (b_1) good conductors of heat,
  (b_2) bad conductors of heat.

Classes a_1, a_2, and b_1 absorb the greater part of the infra-red rays in layers of slight thickness ; but class b_2 is made up of a few substances which are eminently transmissive of these low temperature rays, and we find that radiation from the interior of a body cannot be excluded in even the roughest attempt at a classification. Moreover, under certain circumstances, the same body may have affinities with several classes.

A point which needs to be emphasized is the compensation involved in the radiation of interior layers, together with the thermal replenishing of surface layers by conduction, and the consequent narrowing of the range of temperature and radiant emissivity in different materials, after prolonged insolation.

PLATE VIII.


Subsurface Thermal Gradients.
At the beginning of insolation.
After prolonged insolation.
a1
1
2
a2
3
4
b1
5
6
b2
7
8

Considerable duration of exposure to the heating rays may be needed to affect compensation, but the great length of the lunar day gives ample time for bringing substances having the widest diversity of conductive and absorptive properties to approximately the same temperature. Given unlimited depth of absorbent material, the thermal subsurface gradients of the different classes, when first exposed to radiation, and after prolonged insolation, are indicated diagrammatically in Figs. 1 to 8, Plate VIII, abscissæ being depths, and ordinates temperatures.

Internal absorption of radiation by the transmissive substances of class b_2 gives the effect of almost perfect conductivity. The initial rise of temperature is small, but the internal distribution of heat approaches uniformity, and reaches great depths. In the end, a high temperature is maintained to a great distance from the surface, and the general effect of the combined rays from all depths of this large mass is similar to that of a nearly perfect radiator. Prolonged exposure largely evens up differences of absorbent or of conductive power. Good absorbents of slight conductivity (class a_2) attain a high surface temperature quickly, and further exposure chiefly affects the internal distribution of heat. Class b_1 is composed of metals, in which reflected radiation, represented symbolically in Figs. 5 and 6 as an excess of apparent surface temperature, is large.

The chief point to be noted is that if exposure to solar radiation is sufficiently prolonged to give a stable subsurface temperature-gradient, a large part of the absorbed radiation is re-radiated with but little delay, and the combined emission and reflection from both good and bad radiators is very nearly equal to the radiation simultaneously received. This is a fact of importance in the present case, since it greatly narrows the uncertainty which attaches to the interpretation of observations.

The term emissive power, or emissivity, is sometimes used in a loose way for loss of heat from the unit of surface of an isolated body by radiation and convection combined, and, as so used, is dependent on such a wide range of variable conditions as to be ill adapted to purposes of scientific definition; but, even

when so restricted as to mean loss of heat from the unit of surface by radiation in a vacuum, emissivity, or absolute radiative power, is still a quantity depending on a large variety of circumstances.

A common method of determining relative emissivities of solids at a particular temperature is to coat the faces of a Leslie's cube with thin layers of the various substances, and to compare the radiation from these faces, either in totality by thermopile or bolometer, or analyzed as spectral energy-curves by the spectrobolometer. This involves the assumption that radiation is a surface phenomenon ; and the endeavor is to measure the radiation from a surface of a given material at a definite temperature. It is needless to say that the assumption is incorrect. No substance is absolutely opaque. It is not merely a surface layer of molecules which radiates, but deeper and deeper layers contribute to the effect, of course in relatively smaller and smaller proportion. If the coating be thin, it transmits rays proceeding from the underlying material. If the coating be thick enough to prevent the transmission of rays from a second substance, it is in general no longer permissible to assume that the outer surface is at the same temperature as the well-stirred liquid within the cube. Indeed, there must, in any case, be a temperature-gradient from the outer to the inner surface of the combined solids, and one which, as Leslie's cubes are commonly constructed, is by no means negligible. The best cube is one with walls of very thin and conductive sheet-metal, such as copper, with a reciprocating brush-stirrer, by which the layers of liquid adherent to the inner faces are continually removed and mixed more effectually than by unaided convection. The ideal aimed at is a knowledge of the amount and quality of the radiation from a given material at a definite temperature. The result attained is only approximate, even for highly absorbent substances which can be used in very thin layers, and does not give us information as to the radiation from a considerable mass of transmissive and slightly conductive material gradually heating in the sunshine, for here internal conductivity comes into

play, establishing a temperature-gradient beneath the surface, the radiation proceeding from layers at different temperatures whose range, constituting the gradient, is determined by the conductivity and the coefficient of transmission. Since transparent bodies are poor conductors of heat, while the highly conductive metals are very opaque, it follows that there is a certain degree of compensation in the radiation of various cooling bodies, those bodies in which a rapid flow of heat maintains a high surface temperature during cooling, radiating by means of a very thin layer, but the poor conductors, in which the surface layers are at a lower temperature, radiating from greater depths.

A plate of rock-salt, 5^{cm} thick, heated to 95° C., and compared with a black screen at 20°, the excess being 75°, gave a radiation of 150 arbitrary units (see Table 1). I estimate, graphically, that a block of salt 100^{cm} thick might give 350 arbitrary units. In studying the radiation from such a thick block of highly transmissive substance, after long heating, it is not necessary to consider the distribution of temperature near the surface, since very little of the radiation comes from the outer layers affected by the internal temperature-gradient produced by convective cooling, at least not until the cooling has progressed considerably.

A layer of lampblack not over $0^{cm}.05$ thick (perhaps $0^{cm}.03$ to $0^{cm}.5$) deposited on copper (temperature 99° C., black comparison screen 26°, excess 73°) gave with the same instruments a radiation of 507, which is very near the maximum obtainable from this combination. Reduced to the same excess of 75° C., the radiation of sooted copper is 521. This is 10 to 15 per cent. greater than the radiation of lampblack would be without a metal backing. Compare initial radiation of lampblack on thick glass (Table 2), and radiation of lampblack on thin glass containing mercury (Table 4), allowing for the difference in temperature, and noting that the difference of radiation and surface temperature would be very much greater, if the cooling were prolonged, and that a large amount of heat is removed by

the evaporation of water in experiment IV. For a short exposure, the conductivity of lampblack being very small (about 0.0002), the radiation is that of a thin layer of carbon, let us say $0^{cm}.05$ thick.

The radiation of glass is 93 per cent. of that of lampblack (see Table 5). Glass has about ten times the conductivity of finely powdered carbon, but is more absorbent for long waves, and, owing to this compensation, the depth of its efficient radiant layer may be taken the same as for subdivided carbon with similar backing, or $0^{cm}.05$. By direct experiment, I have found scarcely any difference between the radiation from $\frac{1}{2}^{mm}$ and from 2^{cm} of glass, the thicker layer giving a barely perceptible increase, showing that the adopted thickness cannot be far from the truth.

For the efficient radiating layer of copper, a thickness of $0^{cm}.000001$ may be adopted provisionally. In spite of the high conductivity of copper, the small thickness of the radiating layer causes its radiation to fall far below that of the other substances. Freshly scoured, but not burnished, copper gave a radiation of 64, reduced to the same excess of 75° C. (see Table 1, *d*). Collating these data, we have:

TABLE A.

Substance	Thickness of radiating layer	Conductivity	Radiation	Volumetric radiation	Transparency for self-radiation
	cm.				
Carbon	0.05	0.0002	521	10420.	0.000096
Glass	0.05	0.0020	485	9700.	0.000103
Rock-salt.....	100.	0.0110	350	3.5	0.29
Copper	0.000001	1.0	64	64000000.	0.000000016

The reciprocals of the volumetric radiations, or of equivalent radiations from efficient layers of equal thickness, which are given in the last column, are approximately proportional to the transparency of the materials for the complex of self radiation, although reversal of position may occur in closely succeeding members of the series, as already suggested above in the

case of glass and lampblack with varied backing, owing to differences of conductivity. It is hardly necessary for me to say that no experiments have been made on the radiation of so great a thickness of rock-salt as one meter. I have never seen a block of clear rock-salt approaching that size, and it is quite possible that with pure material the effective radiant depth would be *many* meters, and that in this case this feebly radiant substance might stand at the head of the list when radiating in mass of unlimited depth. But while the results given in Table A are somewhat rude, it seems to me that, as thus stated, they have a meaning, and a practical applicability, which is lacking in the tabular statements of relative emissivities which do service in most of our text books. A single example of the fallacies which underlie many of these numerical statements must suffice. Tyndall, in his *Contributions to Molecular Physics* (p. 248) states that "MM. de la Provostaye and Desains find the relative emissive powers of the two substances [glass and rock-salt] to be as 17 to 6;" and in a later part of the book he gives some results of his own on the relative radiative power of a number of substances, including rock-salt. To show how little real meaning attaches to some of these comparisons, let it be noted that the powdered salt was applied as a thin layer to a metallic cube. Although it is probable that with less transmissive substances the discontinuity of the particles will diminish the rays from the underlying metal by successive reflections, even to the point of extinction, nevertheless it is certain that with powdered salt a large part of the radiation was that of the metal under it.

Two experiments are described:

a. When rock-salt powder was held by sulphur cement, its radiation was 35.3, that of lampblack being 84.

b. When the rock-salt powder was held by electric attraction, its radiation was 24.5, that of black oxide of iron being 65.8 (*loc. cit.*, p. 320 and 321).

Testing further the transmission of these alleged rock-salt rays, Tyndall found that a rock-salt plate, 0.8 inch ($2^{cm}.03$) thick, transmitted—

67.2 per cent. of supposed rock-salt radiation (condition *a*)
62.8 " " " " " " (condition *b*)
(*loc. cit.*, p. 322).

Now I found that using radiation from a block of clear rock-salt, 5^{cm} thick, and with polished faces, instead of the powdered salt on a metal ground (see Table 1), a much thinner plane-surfaced and polished plate of rock-salt, perfectly clear (thickness, $1^{cm}.14 = 0.^{in}.45$), transmitted only 50.8 per cent. of the genuine rock-salt radiations; and since a plate of cold rock-salt $5^{cm}.38$ thick, transmitted 35.1 per cent. of the radiation from a similar hot plate, it may be concluded that a plate of the thickness used by Tyndall will allow 45 per cent. of rock-salt radiation to pass, and by no means so large a quantity as 65 per cent. In all of these measures, the relatively insignificant loss by surface reflection is included with loss by absorption in the body of the medium. As indicated by the dispersion researches of Rubens and Nichols (*Phys. Rev.* **5**, 162, Sept. 1897), the proper radiations of rock-salt presumably approach a wave-length of 50μ. For ordinary sources whose spectral energy-curves have maxima at wave-lengths not so extreme, the absorption is very much less. Thus the rock-salt plate, $5^{cm}.38$ thick, transmits 74.1 per. cent. of the radiation from sooted copper, and 73 per cent. of the radiation from bright copper; from all of which it is evident that Tyndall's value for rock-salt transmission is intermediate between the transmission of this substance for its own and for metallic radiations; and granting that the polish of his surfaces was as good as mine (which owed their perfection to Brashear's unrivaled skill), something over half the radiation from the powdered metal was metallic, while if Tyndall's transmitting surfaces were less perfect, a still larger percentage of the combined radiation must have been due to the metal, and but little to the salt.

Owing to the great conductivity of copper, a considerable mass of this substance continues to radiate for a long time with only slight change, while glass, being a poor conductor, falls off rapidly in its radiation, as is evident from successive values in

Table 2; and the same would be true for lampblack if it were not backed by metal. After some time spent in cooling, glass in mass will radiate less than copper in mass. Rock-salt, owing to the great depths from which the rays proceed, in spite of the feebleness of its volumetric radiation, must eventually surpass all other substances as a radiator. Thus the combination of diverse properties tends to equalize radiant effects in large masses, and with lapse of time, which is not a little remarkable when it is remembered that the volumetric radiating power of these various substances is so different. To be told that the radiating powers of equal efficient volumes of copper and of rock-salt are something like 20,000,000 to 1, and that nevertheless the rock-salt is the better radiator in large masses, is rather startling, but it illustrates the power of compensation.

The substances used in my measures are fairly typical of the following classes:

1. Lampblacked copper is a good radiator of slight transmissive power, but with tolerably rapid transference of heat to the surface. Water, which covers so large a part of the globe, is in nearly the same case. A block of ice at zero Centigrade, radiates almost identically with lampblacked copper of the same temperature. Two sets of measurements gave me:

For ice, 13.6 $\pm$ 0.23, and
For sooted copper, 14.0 $\pm$ 0.15.

Liquid water radiates more powerfully than lampblack, according to Péclet, who found the radiation of water 32 per cent. greater than that of lampblack on metal. I do not know what precautions were taken to eliminate the influence of water vapor from the heated liquid, nor whether the lampblack had a thickness of maximum efficiency, but admitting the reliability of the measurement, it seems that liquid convection is more efficient in maintaining surface temperature, than metallic conduction, hampered by the retardation of so bad a conductor as lampblack.

2. Glass will serve as a representative of a very large class, including most of the surface rocks. Measurements by W.

Hopkins (*Proc. R. Soc.*, **10**, 514, 1860) made in a unit of 1000 grain-degrees Centigrade per square foot per minute, equivalent to 1.16×10^{-3} C. G. S. units, gave the following values of radiation in a vacuum at moderate temperatures per degree Centigrade per square centimeter per second:

Glass	0.000 0856 (C. G. S.)
Chalk	0.000 0871
Sandstone	0.000 0795
Polished limestone	0.000 0815
Unpolished "	0.000 1146 (same block).

These values are not absolute. They were obtained by a calorimetric method involving cooling through a wide range of temperature and the formation of an internal heat-gradient, since the substances are poor conductors. Hence the results are smaller than would be obtained by direct measures of initial radiation at the same temperature.

The initial radiation of glass, at temperatures not much below the boiling point of water, and in nearly normal direction, is 93 per cent. of that of carbon (Table 5), and allowing for the smaller radiation of glass at large angles of emission, its radiation to a hemisphere is about 85.7 per cent. that of carbon; but taking the absolute radiation of carbon at 50°C., or the radiation of carbon to absolute zero for an excess of 323° absolute, as a transferring of 0.0126 small calories per square cm. per second, and the rate per degree Centigrade at this temperature as 0.000128, which is given by Bottomley's measures for sooted copper, the absolute radiation of glass at the same temperature is $0.857 \times 0.0126 = 0.0108$, and its rate per degree 0.000110; and this also represents fairly well the unimpeded radiation from a surface of bare rock in full sunshine, where the renewal of heat from the outside maintains the initial temperature. Hopkins' values suit better for cooling rocks soon after removal of the Sun's rays.

3. Salt covers the surface in some parts of the Earth, but generally in so impure a condition that the relatively large radiation indicated by experiments for deep layers of pure salt, can-

not be expected. A mere incrustation will give a value not far removed from that of the underlying rock. On this Earth, saline crusts cover only a small part of the surface; but it is possible that in such an arid world as the Moon, salt deposits are very extensive. Nevertheless, although salt may be a large ingredient in lunar surface formations, it is certain that few areas on the Moon are white enough to be composed of anything like pure salt; and it is also probable that the original surface lies buried under deposits of cosmic dust.

4. It becomes increasingly probable that cosmic dust is largely metallic, but since its particles are apt to be incrusted by oxidation, such radiating surfaces if composed, for example, of magnetic oxide of iron, or black oxide of manganese, are more nearly represented by sooted than by bright copper, and I am inclined to think that sooted copper is not a bad choice for a comparison body in trying to arrive at a knowledge of the Moon's surface-temperature. Somewhere between this radiative standard and sunlit rock-surface which, as we have seen, does not fall very far below it in efficiency, the emissivity of a considerable part of the lunar surface is likely to be found.

It has been with the design of furnishing a legitimate means of interpreting measures of lunar radiation, and arriving at a better knowledge of the lunar temperature, that I have undertaken these measurements which now follow in detail:

TABLE I.

EXPERIMENTS WITH ROCK-SALT.

a. After being heated for two hours in a hot-air chamber, a rock-salt plate, $5^{cm}.03$ thick, was placed in front of a black copper screen containing water at the temperature of the room, and exposed to the bolometer by removing a similar screen.

a_1. Salt at 85°.6 C. Screen 24°.0. Excess 61°.6 C.

a_2. After heating one-half hour longer: Salt at 86°.8 C. Screen 24°.4. Excess 62°.4 C.

a_3. An absorbent plate of clear rock-salt, $1^{cm}.14$ thick, covered the aperture of the bolometer case, reducing the aperture

in the ratio 23 : 17, whence the deflections must be multipled by 1.35 to be comparable with the others. Same temperature.

a_4. Absorbent plate away. Comparable with a_2 and a_3. Relative humidity 39 per cent. Dew point 11°.1 C., 10.0 grams of water per cubic meter of air.

Radiation:	a_1 div.	a_2 div.	a_3 div.	a_4 div.
	108.5	110.6	41.5	109.6
	108.5	112.1	43.4	110.8
	109.1	107.5	42.0	111.2
	106.3	108.3	39.7	111.3
	107.3	107.3	40.3	110.5
Mean	107.9	109.2	41.4	110.7

Transmission of rock-salt radiation by $1^{cm}.14$ of rock-salt $= \frac{41.4 \times 1.35}{110.0} = 0.508$. Absorption = 49.2 per cent.

b. Rock-salt plate, $5^{cm}.03$ thick, at 95° C. Comparison screens 20°. Excess 75° C.

b_1. Hot salt radiating freely.

b_2. Radiation absorbed by a plate of clear rock-salt, $5^{cm}.38$ thick.

b_3. Hot salt radiating freely. The temperature of the salt has evidently fallen slightly. Relative humidity 31 per cent. Dew point 6°.1 C., 7.27 grams of water per cubic meter of air.

Radiation:	b_1 div.	b_2 div.		b_3 div.
	149.5	47.5	48.2	132
	147	47.9	48.6	126
	145	51.0	47.9	126.5
	148.5	48.4	46.5	126
	145	47.7	47.6	125
Mean	147	48.1		127.1

Transmission of rock-salt radiation by $5^{cm}.38$ of rock-salt $= \frac{48.1}{137.} = 0.351$. Absorption = 64.9 per cent.

c. A bright copper screen was freshly sooted to a thickness, as nearly as could be estimated, of $0^{cm}.03$ to $0^{cm}.05$, until a maximum radiation was obtained.

c_1. Sooted copper screen with boiling water at 99° C.; blackened copper comparison screen, 25°.4. Excess of temperature, 73°.6 C.

c_2. Sooted copper at 99° C., radiating through a plate of clear rock-salt $5^{cm}.38$ thick, at the temperature of the room. Relative humidity, 22 per cent.; dew point, 6°.7 C.; 7.56 grams of water per cubic meter of air.

Radiation:	c_1	c_2
	div.	div.
	504	378.5
	506	375
	503	373.5
	507	373.5
	507.5	378.5
	509	379
	505.5	373.5
	504.5	374.5
	511	378
	514	375.5
Mean	507.2	376.0

Transmission of radiation from thickly sooted copper by $5^{cm}.38$ of rock salt.

$$\frac{376.0}{507.2} = 0.741$$

Absorption 25.9 per cent.

d. A screen of bright copper was freshly scoured with turpentine and pumice, and wiped dry, but was not burnished.

d_1. Bright copper screen, filled with boiling water at 99° C.; blackened copper comparison screen at 24°.6. Excess of temperature, 74°.4 C.

d_2. Bright copper at 99° C., radiating through $5^{cm}.38$ of clear rock salt at the temperature of the room.

Humidity as in experiment *c*.

Radiation:	d_1	d_2
	div.	div.
	60.6	47.1
	66.1	49.1
	64.0	44.7
	63.9	47.9
	62.6	42.7
Mean	63.4	46.3

Transmission of radiation from bright copper by $5^{cm}.38$ of rock salt.

$$\frac{46.3}{63.4} = 0.730$$

Absorption 27.0 per cent.

TABLE II.

EXPERIMENTS WITH GLASS.

a. Two pieces of glass, one $0^{cm}.18$ thick, the other $1^{cm}.97$ thick, were heated in an air-bath for four hours, and upon removal were placed in front of the bolometer. The rapid diminution of successive deflections may be contrasted with the comparative constancy of rock-salt radiation and temperature. Conduction of heat from the interior enables the larger mass to preserve its radiating power better, but allowing for the greater rapidity of cooling of the thin piece, there does not seem to have been much difference in the initial radiation and surface temperature of the thick and thin glass, and this preliminary experiment indicates that the radiation cannot proceed from any great depth.

Glass $0^{cm}.18$ thick.

	div.	div.	
Radiation:	339.5	first diff. 57.0	= cooling in 20 sec.
	282.5	34.5	" " "
	248.0	37.0	" " "
	211.0	29.0	" " "
	182.0		

Glass 1^{cm}.97 thick.

	div.		div.		
Radiation:	379.0	first diff.	17.5	= cooling in 20 sec,	
	361.5		10.5	"	"
	351.0		4.0	"	"
	347.0		6.0	"	"
	341.0				

b. Comparison of radiation from glass and lampblack. The glass plate, 1^{cm}.97 thick, was sooted on one side until quite opaque, and heated for five hours in an air-bath at 99° C. Exposures were made by withdrawing a blackened cold screen at 24°.5 C., the black and clear faces of the glass being alternately turned towards the bolometer. It will be seen by comparing the first deflection, taken immediately after the removal of the glass from the hot air-bath, with Table I, *c*, that the radiation of lampblack on glass is considerably less than that of lampblack on copper. No instrumental correction is needed in this comparison, and temperatures are similar.

Relative humidity, 37 per cent.; dew point, 9°.7 C.; 9.16 grams of water per cubic meter of air.

Face of glass exposed		Ratio of radiation			$\frac{\text{Glass}}{\text{Lampblack}}$
Black	Clear				
415					
	365.5	$\frac{366.5}{397.5}$	=	0.922	
380					
	344	$\frac{344.0}{366.5}$	=	0.939	
353					
	319.5	$\frac{319.5}{340.3}$	=	0.939	0.9322
327.5					
	294.5	$\frac{294.5}{317.0}$	=	0.929	
306.5					
	276	$\frac{276.0}{296.0}$	=	0.932	
285.5					
	257.5	$\frac{257.5}{273.8}$	=	0.940	
262					
	242	$\frac{242.0}{253.0}$	=	0.957	
244					
	219	$\frac{219.0}{236.0}$	=	0.928	0.9396
228					
	204.5	$\frac{204.5}{218.8}$	=	0.935	
209.5					
	190	$\frac{190.0}{202.5}$	=	0.938	
195.5					

TABLE III.

EXPERIMENTS WITH THIN GLASS BACKED BY WATER.

One-half of the cylindrical surface of a large glass beaker was coated with lampblack until opaque for the Sun's light. The beaker, filled with boiling water (temperature 98°.5 C.), was taken from the fire for each exposure, and placed at a marked point in line with the axis of the bolometer case and in front of a blackened comparison screen at 20° C. After the deflection was recorded, the glass vessel was restored to the fire, and as soon as it was again in vigorous ebullition, the experiment was repeated with the opposite face of the beaker turned toward the bolometer. The radiation from the clear side is that of glass, $\frac{1}{2}^{mm}$ thick, together with a feeble trace of radiation from water.

	Face of glass exposed		Ratio of radiation		$\frac{\text{Glass}}{\text{Lampblack}}$
	Black	Clear			
First series	485.5	445.0	$\frac{445.0}{47.88}$	= 0.929	0.9236
	472.0	446.0	$\frac{446.0}{475.8}$	= 0.937	
	479.5	445.0	$\frac{445.0}{486.5}$	= 0.915	
	493.5	445.0	$\frac{445.0}{488.5}$	= 0.911	
	483.5	450.5	$\frac{450.5}{486.5}$	= 0.926	
	489.5				
Second series	505.0	466.0	$\frac{466.0}{505.0}$	= 0.923	0.9232
	505.0	472.5	$\frac{472.5}{506.8}$	= 0.932	
	508.5	465.0	$\frac{465.0}{509.0}$	= 0.914	
	509.5	474.0	$\frac{474.0}{512.3}$	= 0.925	
	515.0	470.5	$\frac{470.5}{510.5}$	= 0.922	
	506.0				

Relative humidity 34 per cent.; dew point 6°.9 C.; 7.65 grams of water per cubic meter.

TABLE IV.

EXPERIMENTS WITH THIN GLASS BACKED BY MERCURY.

A large glass beaker, with walls ½ mm thick, was prepared with an inner smaller beaker held concentrically by cork plugs, the space between the two being filled with mercury, and the inner one with water. One-half of the outer surface was blackened by camphor smoke until completely opaque. The vessel was heated until the water began to boil, and was then taken from the fire and allowed to cool for about two minutes, in order that the mercury might fall to approximately the same temperature as the water. In the course of a series the temperature fell from about 93° C. to 73° C. Exposures were made, as in experiment III, by replacing the black comparison screen by the hot vessel.

First and second series: comparison screen 28° C.; relative humidity 41 per cent.; dew point 14°.4 C.; 12.26 grams of water per cubic meter of air. Third series: comparison screen 25°.3 C.; relative humidity 51 per cent.; dew point 14°.4 C.; 12.26 grams of water per cubic meter of air.

	Face of glass exposed		Ratio of radiation	Glass / Lampblack
	Black	Clear		
First series	421.5	375	$\frac{375}{403.3}$ =	0.930
	385	341	$\frac{341}{368.5}$ =	0.925
	352	311	$\frac{311}{336.5}$ =	0.924
	321	290.5	$\frac{290.5}{306}$ =	0.949
	291	267	$\frac{267}{281.0}$ =	0.950
	271			
			Mean	0.9356

Second series	408	357	$\frac{357}{387.5}$	= 0.921
	367	324.5	$\frac{324.5}{352.3}$	= 0.921
	337.5	298	$\frac{298}{321.0}$	= 0.928
	304.5	275	$\frac{275}{293.8}$	= 0.936
	283	248	$\frac{248}{271.8}$	= 0.912
	260.5			
			Mean	0.9236
Third series	391.5	354.5	$\frac{354.5}{377.5}$	= 0.939
	363.5	331.5	$\frac{331.5}{352.0}$	= 0.942
	340.5	307	$\frac{307}{329.0}$	= 0.933
	317.5	283.5	$\frac{283.5}{307.3}$	= 0.923
	297	267.5	$\frac{267.5}{287.0}$	= 0.932
	277			
			Mean	0.9338

No change in the ratio of radiations from glass and lampblack was produced by the interposition of a thick plate of rock-salt, the series giving the ratio 0.9274.

TABLE V.

SUMMARY OF EXPERIMENTS ON THE RADIATION OF GLASS AND LAMPBLACK.

Comparisons by several methods furnish nearly the same value for this important ratio.

Radiator	Radiation of glass / Radiation of lampblack		
Thin glass backed by water,	0.9236	±	0.0035
" " " " "	0.9232	±	0.0018
" " (absorbed by rock-salt)	0.9274	±	0.0032
Thick glass, - - -	0.9322	±	0.0023
" " - - -	0.9396	±	0.0030
Thin glass backed by mercury,	0.9356	±	0.0047
" " " " "	0.9236	±	0.0029
" " " " "	0.9338	±	0.0023
Radiation of glass =	0.9299		
" " lampblack =	1.0000		

A glass vessel with thin walls, nearly normal to the direction of emission, and containing a boiling liquid of nearly constant temperature, with screens arranged to shut out radiation from hot vapors, constitutes a good standard of radiation, perhaps better than either lampblack on metal, or polished metal; for unless special precautions are taken to get a thick coat of fresh lampblack whenever the comparison screen is used, the maximum efficiency of a blackened screen is seldom obtained, and the emission of bright metal varies with its polish, or its tarnish.

A SIMPLE INTERPOLATION FORMULA FOR THE PRISMATIC SPECTRUM.

By J. HARTMANN.

THE Appendix to the twelfth volume of the Publications of the Astrophysical Observatory at Potsdam, contains a new dispersion formula proposed by myself, which is worthy of attention on account of its great simplicity and accuracy. I beg to present here an abstract of that article.

When λ denotes the wave-length and n the index of refraction the new formula reads

$$n = n_0 + \frac{c}{(\lambda - \lambda_0)^a},$$

where n_0, λ, c, and a are constants depending upon the substance of which the prism is made. For the kinds of crown and flint glass in ordinary use, $a = 1.2$, so that for a glass prism it only remains to calculate the three constants n_0, λ_0, and c from the measures. In the above reference I have given a very simple method for making this computation, and here I shall only show by an example how accurately the indices of refraction can be represented by the formula. The measurements of indices by Professor Müller given in the fourth volume of the Potsdam Publications are, on account of their high accuracy, especially adapted for testing a dispersion formula. The following table contains in the second column the wave-lengths (Potsdam system) of the observed lines, in the third column the indices reduced to 0° C, as measured by Professor Müller on the flint prism designated as No. 3, and in the fourth column the probable errors in units of the sixth decimal of n. The sixth column gives the values of n resulting from the employment of Cauchy's formula heretofore most often used, viz.,

$$n = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}.$$

The constants of this formula, calculated by the method of least

squares from the whole series of measures, are $a = 1.5604998$, $b = 0.006216900$, $c = 0.000168871$. The residuals O — C in units of the sixth decimal place follow. The last two columns contain the indices and their residuals as calculated from the new formula. The values of the constants of this formula for the flint glass used are $n_0 = 1.555166$, $\lambda_0 = 0.17060$, $\lg c = 7.938724$.

Line	λ	n	P. E.	Cauchy		Hartmann	
				n	O−C	n	O−C
B	0μ.68685	1.574359	± 5.0	1.574436	−77	1.574365	− 6
C	0 .65631	1.575828	6.2	1.575843	−15	1.575823	+ 5
α	0 .62780	1.577377	6.3	1.577361	+16	1.577378	− 1
D	0 .58932	1.579855	6.8	1.579800	+55	1.579850	+ 5
0μ.55	0 .55287	1.582703	7.2	1.582646	+57	1.582703	0
b_1	0 .51839	1.585999	3.7	1.585972	+27	1.586008	− 9
F	0 .48616	1.589828	3.9	1.589826	+ 2	1.589826	+ 2
0μ.47	0 .46678	1.592565	4.6	1.592590	−25	1.592565	0
Hγ	0 .43407	1.598204	5.0	1.598252	−48	1.598203	+ 1
g	0 .42271	1.600543	5.2	1.600582	−39	1.600541	+ 2
h	0 .41020	1.603398	2.7	1.603412	−14	1.603399	− 1
H_1	0 .39688	1.606838	12.4	1.606775	+63	1.606826	+12

The great advantage of the new formula is clearly apparent from a comparison of the two columns O — C, for while the residuals of Cauchy's formula show a systematic progress, and exceed the probable error by almost tenfold, the deviations of the new formula from the observations lie within the limits of error of the observations and their signs are quite irregularly distributed.

But in addition to its good representation of the dispersion curve the formula has the second very important property of being readily solved for the wave-length λ, which is not the case for any of the previous dispersion formulæ. The formula thus solved for λ,

$$\lambda = \lambda_0 + \frac{c}{(n - n_0)^{\frac{1}{a}}},$$

in which $\frac{1}{a}$ is about $\frac{5}{6}$, would serve for the calculation of the wave-length corresponding to a given index of refraction; and since further the index varies in a well-known manner with the

minimum of deviation, the wave-length of the line observed could be computed from the measured minimum of deviation. It appears, however, that two simplifications are permissible which make the determination of wave-lengths in the prismatic spectrum much more convenient. Since it is in practice usually not possible to observe the whole of the visible spectrum without alterations of the adjustments, especially of the focusing of the spectroscope, the accuracy of the interpolation formula will be sufficient if it exactly represents the dispersion for shorter portions of the spectrum, say for differences of $100^{\mu\mu}$ in wave-length. This condition is fulfilled by the simplified formula

$$\lambda = \lambda_0 + \frac{c}{n - n_0},$$

in which a has been placed equal to 1. Further, in place of the index n we may put the directly observed quantities dependent upon it — first the minima of deviation, then the deviations measured with stationary prism, and finally their projections on a plane scale, as in the use of a comparison scale in the spectroscope or as in the examination of photographic spectra. When a spectrogram is measured with a micrometer screw we may accordingly put in the micrometer reading directly for n. Although the use of the new formula has thus been shown to be very simple, yet in practical calculation still further simplicity results from the meaning of the three constants, λ_0, n_0 and c. A moment's reflection shows that n_0 is dependent only upon the zero-point chosen for counting the divisions of the screw or scale, so that n_0 may be termed the zero-point, while c represents the value of the revolution of the screw or of a division of the scale. λ_0 is a constant for each spectroscope, and needs be determined but once for each instrument.

In order to exhibit how accurately the formula satisfied the observations, I give in the following table the results of the measurement of a photograph of the solar spectrum obtained here with a stellar spectrograph. The entire length of the spectrum from F to M was but 48^{mm}. The direct readings of the micrometer screw are given under n, and the wave-lengths of

the measured lines from Rowland's atlas under λ, while the column λ' contains the wave-lengths calculated from the formula

$$\lambda' = 223.28 + \frac{[4.819004]}{404.251 - n}.$$

The constants of this formula were determined from three properly selected lines.

Line	n	λ	λ'	O-C
	R	$\mu\mu$	$\mu\mu$	$\mu\mu$
	17.794	370.96	370.93	+0.03
	23.130	372.71	372.72	−0.01
M	23.323	372.77	372.78	−0.01
	27.928	374.36	374.36	0.00
	29.298	374.85	374.84	+0.01
	32.492	375.95	375.96	−0.01
	33.035	376.15	376.15	0.00
	34.219	376.58	376.57	+0.01
	40.406	378.80	378.81	−0.01
	42.351	379.50	379.53	−0.03
	43.574	379.97	379.98	−0.01
	47.135	381.31	381.32	−0.01
	53.699	383.85	383.84	+0.01
	54.341	384.10	384.10	0.00
	60.555	386.58	386.57	+0.01
	63.696	387.86	387.85	+0.01
	67.834	389.57	389.57	0.00
	69.590	390.32	390.31	+0.01
	70.195	390.58	390.57	+0.01
	74.254	392.30	392.31	−0.01
	75.414	392.82	392.81	+0.01
	81.060	395.30	395.31	−0.01
	82.961	396.17	396.17	0.00
	92.349	400.52	400.53	−0.01
	100.677	404.60	404.59	+0.01
	104.224	406.39	406.38	+0.01
h	111.542	410.19	410.18	+0.01
	119.307	414.39	414.38	+0.01
	129.516	420.21	420.21	0.00
g	133.685	422.70	422.69	+0.01
	140.938	427.17	427.17	0.00
G	146.598	430.80	430.80	0.00
Hγ	151.535	434.07	434.08	−0.01
	157.787	438.37	438.38	−0.01
	160.793	440.50	440.51	−0.01
	193.579	466.80	466.82	−0.02
F	213.523	486.17	486.19	−0.02
b_4	239.565	516.77	516.66	+0.11
b_2	239.991	517.28	517.22	+0.06
b_1	240.820	518.39	518.32	+0.07

Aside from the b lines, which do not appear quite sharp on the photograph so that their measures are somewhat uncertain, the whole portion of the spectrum embracing a difference of wave-length of $115^{\mu\mu}$ is represented with absolute accuracy by the formula. The small residuals under $O-C$, as is evident from the irregular distribution of their signs, are to be assigned to errors of observation.

POTSDAM ASTROPHYSICAL OBSERVATORY.

RÉSUMÉ OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE FIRST HALF OF 1898.

By P. TACCHINI.

I GIVE below a résumé of the solar observations made here during the first half of 1898. We have enjoyed a fairly good winter, and consequently a considerable number of observations have been made. The results for the spots and faculæ are given in the following table:

1898	Number of days of observation	Relative frequency		Relative size		Number of spot groups per day
		of spots	of days without spots	of spots	of faculæ	
January	25	7.84	0.00	37.8	71.6	2.7
February	22	14.64	0.14	50.1	72.3	2.9
March	20	10.40	0.20	48.5	83.5	2.3
April	18	6.17	0.17	16.3	130.0	1.7
May	26	6.96	0.00	24.9	98.4	1.7
June	21	4.57	0.33	7.7	87.1	1.5

For the prominences we have obtained the following results:

1898	Number of days of observation	Mean number	Prominences	
			Mean height	Mean extent
January	18	2.67	31″.5	1°.3
February	14	2.57	30 .8	1 .2
March	13	2.38	31 .2	1 .4
April	16	3.44	27 .6	1 .1
May	25	1.08	19 .9	0 .8
June	24	3.00	32 .4	1 .1

After the secondary maximum in February the spots showed a progressive diminution, both in area and in the number of groups; but the minimum in June was not so marked as the minimum of November 1897, deduced from nearly the same

number of observations. It should also be noticed that even the period of small solar activity was not without fine groups, like those of February and March.

It appears from a comparison of these results with those of the preceding six months that the prominences, like the spots, have shown a diminution in activity; the minimum in May is especially remarkable.

The following table gives the distribution in latitude of the various phenomena, arranged by quarters in ten-degree zones.

PROMINENCES.

Latitude	First quarter		Second quarter	
90°+80	0.000		0.000	
80 +70	0.024		0.012	
70 +60	0.032		0.012	
60 +50	0.040		0.055	
50 +40	0.032	0.429	0.025	0.418
40 +30	0.040		0.086	
30 +20	0.055		0.068	
20 +10	0.111		0.068	
10 — 0	0.095		0.092	
0°—10	0.167		0.062	
10 —20	0.079		0.098	
20 —30	0.055		0.147	
30 —40	0.095		0.098	
40 —50	0.079	0.571	0.092	0.582
50 —60	0.040		0.069	
60 —70	0.024		0.012	
70 —80	0.016		0.012	
80 —90	0.016		0.012	

FACULÆ.

60°+50	0.004		0.000	
50 +40	0.000		0.004	
40 +30	0.018		0.026	
30 +20	0.091	0.435	0.053	0.373
20 +10	0.148		0.117	
10 — 0	0.174		0.173	
0°—10	0.213		0.244	
10 —20	0.165		0.233	
20 —30	0.104		0.109	
30 —40	0.061	0.565	0.026	0.627
40 —50	0.018		0.011	
50 —60	0.004		0.004	

SPOTS.

20°+10	0.068	0.273	0.192	0.341
10 — 0	0.205		0.149	
0°—10	0.295	0.727	0.106	0.659
10 —20	0.432		0.553	

The prominences have been most numerous in the southern zones, as was the case in the preceding quarter; they have been seen in almost every zone, with the maximum south of the equator. Like the prominences, the faculæ had their greatest frequency in the southern hemisphere, with the maximum in the zone (0°—10°); they have extended from 0° to ±60°.

The spots have been confined to the equatorial zone, as in the last semester, and they have resembled the prominences and faculæ in the fact that their frequency was greater in the southern zones. The only eruption, a slight one observed March 18, was confined to the region —6°.4 to —9°.

ROME, September 14, 1898.

THE GREAT NEBULA OF ANDROMEDA.

By E. E. Barnard.

In June and July of this year I made a series of measures of the nucleus of the Great Nebula of Andromeda with reference to two 11th magnitude stars—one preceding and the other south.

Following are the measures, the stars being referred to the nucleus:

Nucleus and star *a*

1898	June	27	261°.24	124″.85	
	July	5	261 .15	124 .41	
		11	261 .15	124 .47	
		12	261 .35	124 .97	
		18	261 .23	124 .63	
	Sept.	27	261 .28	124 .85	
			261 .23	124 .70	∴ $\Delta\alpha$ (neb. − *) = +0^m 10^s.84
					$\Delta\delta$ = +0′ 19″.01

Nucleus and star *b*

1898	June	27	160°.65	228″.31	
	July	5	160 .55	228 .57	
		11	160 .45	228 .47	
		12	160 .52	228 .30	
		18	160 .38	228 .46	
			160. 51	228 .42	∴ $\Delta\alpha$ (neb. − *) = −0^m 6^s.70
					$\Delta\delta$ = +3′ 35″.34

A fainter star was also measured on one date:

Nucleus and star *c*, 14^m

1898	July 5	177°.22	157″.87

At each of these measures the nucleus was fairly well seen, though it was not stellar.

It has been my custom, both here and at the Lick Observatory, to frequently examine the great nebula for traces of the Nova of 1885, but nothing has ever been seen of it. During the present measures I carefully looked for the Nova, and on July 11 made the following note:

"Looked carefully for Nova of 1885, with powers 460 and 700, seeing fairly good."

It will be seen, therefore, that I am pretty familiar with the appearance of the nebula.

On September 20, past, a telegram announced the discovery of a starlike condensation in the center of the great nebula by Seraphimoff at Pulkowa.

Later advices seem to show that Seraphimoff's observation was simply a confirmation of the discovery of a starlike body in the great nebula by someone else, presumably Mr. A. A. C. Merlin, British vice-consul at Volo, Greece, who had telegraphed August 29 that he had observed a star near the nucleus of the great nebula.

M. Rayet, of the Lyons Observatory, France, announces in the *Comptes Rendus* for September 26, 1898, that he has verified Seraphimoff's observation and that the change is real.

When the announcement of a change in the nebula was made I had the impression that it must be a reappearance of the Nova of 1885. As soon as darkness permitted, the great telescope was turned on the nebula. It was at once seen that the Nova was not present. It was also evident that no perceptible change had occurred in the nucleus or the nebula itself. Since then this object has been carefully examined a number of times with both the 40-inch and the 12-inch telescopes, and the impression has always been that the nebula is unchanged. The measures of the star *a* on September 27 were made as a confirmation of the previous measures to show that no change had occurred in the position of the nucleus, which appeared the same to me as it did at the previous measures.

The nucleus of this great nebula is so affected by the conditions of seeing, moonlight, etc., that one can readily be deceived by it, if he is not perfectly familiar with its appearance under all conditions. When the air is steady the nucleus is almost stellar, especially with low powers.

If the seeing is not good the nucleus is woolly and faint, and often lost sight of entirely, so that one familiar with it under

these conditions alone would suppose a great change had occurred if he saw the nucleus under the best conditions. Its distinctness is more easily affected than that of a star of the same magnitude for two reasons — first, it is not a stellar point; second, its light would be confused with that of the nebula under conditions of seeing that would scarcely affect a star not situated in a bright nebula.

I think photography would be a more satisfactory test of change than the memory of one not perfectly familiar with the nebula.

From visual observations, I would say that no apparent change has occurred in this great nebula in the past few years.

M. Rayet, in the number of the *Comptes Rendus* referred to, gives his measures of the position of the nucleus and the 11th magnitude star preceding. He also gives the measures of other observers.

Here is the list:

	$\Delta\alpha$	$\Delta\delta$
D'Arrest,	$+0^m\ 11^s.26$	$+0'\ 19''.5$
Struve,	$+0\ 10\ .87$	$+0\ 18\ .7$
Vogel,	$+0\ 10\ .79$	$+0\ 19\ .4$
Rayet,	$+0\ 10\ .91$	$+0\ 18\ .48$
The means are,	$+0\ 10\ .96$	$+0\ 19\ .02$

Dr. R. Engelmann, at Leipzig, in the first part of September 1885, measured the position of the star *a* with reference to the Nova (*A. N.* 2683):

Position angle, $262°.42$ (4) Dist., $109''.72$ (6)

From this, the Nova was nearly on the line from the nucleus to the 11^m star and some $16''$ distant from the nucleus.

Engelmann also measured the position of the nucleus with reference to the Nova:

Position angle, $76°.14$ (8) Dist., $16''.33$ (8)
and hence $\Delta\alpha = +0^m\ 1^s.393$, $\Delta\delta = +0'\ 3''.91$

YERKES OBSERVATORY,
October 21, 1898.

Minor Contributions and Notes

PROCEEDINGS OF THE SECOND CONFERENCE OF ASTRONOMERS AND ASTROPHYSICISTS.

THE following abstracts of papers read, or presented by title, at the Second Conference of Astronomers and Astrophysicists have been prepared by the authors.

PERSONAL EQUATION IN TRANSIT OBSERVATIONS.

In the study of personal equation, we learn only what may happen under special conditions, which may possibly never recur, and the labor demanded by the study often seems excessive in view of its very limited results. This furnishes an excuse for the comparatively superficial investigation of the subject ordinarily undertaken, as in the present instance. Still, some conclusions which seem worth recording have been reached by the experience obtained during the last thirty years at Harvard College Observatory. One of these conclusions is that the micrometrical determination of the collimation error of a transit instrument, by means of collimators or of meridian marks, so commonly disagrees with the result for collimation obtained by the adjustment to each other of a series of transits observed with the same instrument, that it becomes unsafe to depend upon the micrometrical determination in the reduction of the observations. While the results obtained by different observers by means of the collimators agree very closely, and while the error thus determined remains nearly constant for considerable periods of time, the results obtained by the same observers from the discussion of series of transit observations give different results, which are neither so accordant nor so constant as those obtained micrometrically. It may be, of course, that the errors indicated by the transits are not really collimation errors; that is, it may be suspected that some other coefficient than the secant of the declination might be employed in the reductions to better advantage. After trial of various coefficients, however, none have been found to produce as much accordance in the results for different stars as can be

obtained with the secant of the declination. It is therefore provisionally assumed that the discrepancies which have been noticed are due to a personal equation in collimation, in addition to the kind of personal equation usually recognized in transit observations, consisting simply in a difference in the absolute time of the observations made by different persons.

Another form of personal equation in transit observations occasions errors of the kind which might be attributed to a rate of the clock at the time of observation differing from the rate found for it by the comparison of the results for different days. But this supposition is excluded when we find on the same evening different rates derived from the transits observed by different persons.

It also happens that differences occur systematically between different observers with regard to stars in northern and southern declinations equally far from the equator; so that the apparent position of the axis of the instrument, as well as the line of collimation, changes with the observer. This phenomenon is more difficult to understand than those previously mentioned.

Personal equation dependent on stellar magnitude has been for some time an admitted fact, and was merely mentioned in the paper here abridged. We have, accordingly, five kinds of personal equation possible in transit observations: (1) in absolute time, (2) in collimation, (3) in the apparent position of the instrument, (4) in clock rate, (5) in the effect of stellar magnitude.

ARTHUR SEARLE.

SOME INVESTIGATIONS RELATING TO ZENITH TELESCOPE LATITUDES.

A series of latitude determinations by the Talcott method was undertaken by the author in the winter of 1895 for the purpose of investigating the effect of barometric and thermometric gradients in the atmosphere upon zenith telescope latitudes. The instrument employed was an excellent portable transit by Bamberg, and the observing programme comprised chiefly pairs of stars culminating at large zenith distances, in the average about 75°, since the effects sought increase with $\sec^2 z$.

The amount by which a stratum of homogeneous air was tipped from its normal horizontal position was determined for each observing night from the isobars and isotherms of the United States Weather Bureau's weather map for 8 P.M., and the resulting disturbance com-

pared with the observed value of the latitude. During the period of observation the inclinations of the strata varied from $-0''.4$ to $+2''.2$, but no obvious relation exists between these inclinations and the observed latitudes. These latter, however, show very plainly a dependence upon the direction of the wind, being a maximum when the wind comes from the direction of the Observatory chimney, distant about thirty meters from the instrument. The amplitude of this apparent variation in the latitude is approximately one second of arc.

A similar series of observations made in the months of May and June, when the chimney was not heated, shows no such variation, and also shows no marked dependence of the latitude upon the inclination of the air strata, although in this series the inclination of the strata varied from $-1''.6$ to $+2''.8$, and the zenith distances of the stars observed were included between 76° and 87°. Observations at this latter zenith distance, although difficult and of diminished precision, are nevertheless eminently satisfactory for the purpose in hand.

The foregoing results suggest that the variation from night to night in the value of the observed latitude depends upon local conditions rather than upon elements which can be read from a general weather map. That perturbing elements of appreciable magnitude are generally present in zenith telescope work, may be inferred from the following table of recent determinations of the constant of aberration made by the Talcott method, and the remainder of the paper was devoted to a discussion of the local surroundings at the several places of observation with reference to determining their probable effect upon the value of the aberration.

Place	Authority	Observed Aberration Constant	Corr.
Hong Kong	*A. N.*, 3504	$20''.38 \pm 0''.07$	?
Hong Kong	*A. N.*, 3504	20 .43 0 .06	?
Honolulu	*Bull. C. and G. Surv.*	20 .43 0 .03	—
New York	*A. J.*, 401	20 .46 0 .01	?
Strassburg	*V. J. S.*, 1895	20 .47 0 .01	?
San Francisco	*Bull. C. and G. Surv.*	20 .48 0 .03	—
Berlin	*A. N.*, 3015.	20 .49 0 .02	—
Naples	*Nov. Determ.*, Fergola	20 .53 0 .01 (?)	—
Bethlehem	*A. J.*, 406	20 .55 0 .01	—
Cape	*M. N.*, Dec. 1897	20 .58 0 .01	—
Berlin	*A. J.*, 429	20 .61 (?)	—
Hong Kong	*A. N.*, 3504	20 .64 0 .08	?

This effect cannot, in any case, be determined quantitatively, but its sign is indicated in the last column of the table, a + indicating that the observed value should be increased to eliminate the effect of local conditions: *e. g.*, at Naples the diurnal range of temperature north of the Observatory (over the land) is greater than that south of the Observatory (over the sea), whereby stars near the zenith are relatively thrown toward the north in the evening and toward the south in the morning, thus producing too great a value of the aberration. Similarly, at the other stations, an unsymmetrical diurnal variation of temperature is supposed to produce an effect upon the observed value of the aberration.

A more detailed exposition of the subject will be published elsewhere.

G. C. COMSTOCK.

STARS OF THE FIFTH TYPE IN THE MAGELLANIC CLOUDS.

Stars having spectra consisting mainly of bright lines belong to Type V. In 1891 the number of these stars known was thirty-three. Three of these were discovered by Wolf and Rayet, six by Copeland, one by Respighi, three by Pickering, and twenty from the Draper Memorial Photographs of the Harvard College Observatory. In May 1897 the number known was sixty-seven. All of these stars lie closely along the central line of the Milky Way, and, although the sky had been equally well covered with spectrum plates from pole to pole, a careful examination of these plates failed to show any of these stars outside of this region.

On May 26, 1897, an examination of two plates taken at Arequipa with the Bruce telescope, showed a group of six of these objects in the Large Magellanic Cloud. Two later plates add fifteen more in the Large Magellanic Cloud, and these, with three others in the Milky Way, and one in the Small Magellanic Cloud, make the total number of these stars, so far known, ninety-two. Thirteen of these were found visually, all the others have been found from the photographs in the Draper Memorial work. The great advantages of photography in the study of stellar spectra is thus again demonstrated.

The presence of so many stars of the Fifth Type in the Magellanic Clouds establishes another connection between them and the Milky Way.

M. FLEMING.

CLASSIFICATION OF THE SPECTRA OF VARIABLE STARS OF LONG PERIOD.

In the classification of the spectra of stars in the *Draper Catalogue* the letter M was assigned to stars having spectra of the third type. Later these stars were subdivided into four groups, Ma, Mb, Mc and Md, of which α Orionis, α Herculis, $-2^{\circ}3653$, and o Ceti were given as examples. In the last of these stars the hydrogen lines are bright, and this spectrum has been shown to be characteristic of variable stars of long period; indeed, by this peculiarity in the spectrum about a hundred new variables have been found. A further examination of these spectra shows that they can be further subdivided into eleven groups. A classification was made from an examination of the continuous spectrum, the comparative brightness of the hydrogen lines being also carefully estimated, always assuming the brightness of $H\gamma$ as 10. The first class, of which R Lyncis is the typical star, shows a spectrum resembling α Tauri, having also $H\beta$ and $H\gamma$ strongly bright and nearly equal, while $H\delta$ is barely visible. The last group, of which R Leonis is the typical star, shows a continuous spectrum similar to $-2^{\circ}3653$, or a little beyond that star in the classification. Of the bright hydrogen lines in R Leonis $H\beta$ is not seen, $H\gamma$ is barely visible, and $H\delta$ is strongly marked. The other classes form a nearly continuous sequence between these extremes.

M. FLEMING.

VARIABLE STARS IN CLUSTERS.

A systematic search of twenty dense globular clusters by means of photographs made with the 13-inch telescope gives the following results:

Number of stars examined about 18,600.

Number of variables found 501.

In certain clusters no variables have been found; in others very few. The results in four clusters are especially striking.

N. G. C. 5272, Messier 3, out of about 900 stars examined, has 132 variables, nearly 15 per cent.; *N. G. C.* 5904, Messier 5, out of about 900 stars examined, has 85 variables, about 9½ per cent. In *N. G. C.* 7078, 51 stars out of 900, or 6 per cent., and in *N. G. C.* 5139, ω Centauri, 125 out of about 3000, or 4 per cent., have been found variable.

Considerable progress has been made in the discussion of the variables in ω Centauri. The approximate periods and light curves of

105 have been determined. The extreme periods so far found seem to be 475 days in the case of No. 2 and $6^h\ 11^m$ in that of No. 91. Ninety-eight have periods less than 24^h.

These short periods are often characterized by sudden increase in brightness, brief maximum, a relatively slow decrease in brightness, and a considerable interval at or near minimum. On the other hand, in some cases the time of increase is equal to or even greater than that of decrease.

S. I. Bailey.

MERIDIAN OBSERVATIONS FOR STELLAR PARALLAX.

The reduction of the observations made in the years 1893–1896 at the Washburn Observatory, Madison, Wis., of which a report was given at the conference of last October, is now nearly complete.

The Repsold meridian circle of $12^{cm}.2$ aperture was employed in the well-known but comparatively new method of observing meridian transits of each parallax star with two comparison stars. The observing list of nearly one hundred stars comprised over seventy stars of large proper motion, together with binaries, most of which have considerable proper motion. Screens of fine brass wire were employed to reduce the apparent magnitudes of the brighter stars.

The reduction of the present series of parallaxes to the weighted means of good determinations by previous observers, from the thirty stars available, is $0''.03$. Systematic error might be expected mostly on account of larger differences of magnitude between the parallax stars and their comparison stars. These differences range from -2.0 to $+2.0$, the latter sign indicating that the parallax star was fainter. A graphical representation of all the parallaxes shows some appearance of such an error, and it appears to be within the limit $+0''.065$ for a difference of one magnitude in the positive direction. A plot of the differences from previous determinations, on the thirty stars already mentioned, gives a similar indication. This effect appears more marked in several cases which will require further investigation. Extensive observations were made concurrently with the parallax observations upon independent, miscellaneous stars employing the screens in order to control the personal equation dependent upon magnitude.

A plot of the parallaxes according to the right ascensions of the stars gives no plain evidence of seasonal variation. The same holds true of the differences from previous determinations.

The general means of the probable errors of the parallaxes, from the stars most frequently observed, range from $\pm 0''.032$ to $\pm 0''.045$, the former value for stars of higher declination, the latter for those of moderate southern declination. The corresponding probable errors for the observed difference of right ascension of any two stars vary from $\pm 0''.17$ to $\pm 0''.22$. The probable error of a single observation appears not to be affected by such differences as occur in the right ascensions, declinations, or magnitudes of the stars, but is increased materially upon stars too faint for convenient observation.

A graphical representation was made of the parallaxes of the present series according to the proper motions of the stars, in all cases where they were greater than $1''$ with the exception of Groombridge 1830. The plotted points happened to fall into three groups, the apparent centers of which lay on one right line. From this line the following figures for mean parallax corresponding to proper motion are derived :

Proper motion	Parallax	Number of stars
$1''.25$	$0''.10$	40
2 .05	0 .14	13
4 .20	0 .28	5

A new series of parallax observations by this method has been begun. The list consists of 121 parallax stars, second-magnitude stars, binaries, and certain stars of larger proper motion. Instead of repeating the customary method of observation, that of recording transits over a fixed reticule, a Repsold transit-micrometer is employed, and the observer holds the image of a star during transit in bisection between a pair of movable threads.

ALBERT S. FLINT.

THE DIRECT GRATING SPECTROSCOPE.

This paper consisted of a description of a new method of using the concave grating for stellar spectroscopy. Preliminary notes, giving full details of the method in question, were published in the ASTROPHYSICAL JOURNAL for March 1898, and in the *Monthly Notices of the Royal Astronomical Society* for March 1898. Since these notes appeared a much larger grating was especially ruled by Professor Rowland, and this paper embodied the results obtained with this new grating. This grating has a ruled surface of $5\frac{3}{4} \times 2$ inches. The radius of curvature

is 1 meter, and the grating is ruled with 7500 lines to the inch. The definition is excellent.

Many original negatives were exhibited, as well as several enlarged glass positives. The experiments with the larger grating showed that a good photograph of the spectrum of Sirius could be obtained in the second order with an exposure of five minutes. In general, it may be stated that the time of exposure for different stars was very much less than had been currently expected.

CHARLES LANE POOR.

THE EFFECT OF ATMOSPHERIC DISTURBANCE ON TELESCOPIC DEFINITION.

During the past year a number of papers have been published showing the effect of different conditions of the atmosphere on telescopic definition. In a discussion of this nature it is important to discriminate between the effects produced by disturbances directly in front of the object-glass and those in the distant atmosphere.

A cylinder of light the size of the object-glass extends through the whole body of atmosphere, and it is extremely probable that abnormal conditions may exist at different distances from the object-glass.

In the latitude of the United States atmospheric waves are constantly propagated from west to east with a velocity from ten to forty miles per hour. Aside from this, near the surface of the Earth there is a bodily translation of air which may move in any direction. Hence it follows that at every instant the wave-front meets a new stratum of atmosphere. Now when we consider the magnitude of atmospheric waves, the area of the wave-front for the largest telescope in use will be infinitely small as compared with area of the disturbed region, and it is reasonable to assume that the wave-fronts will be in the same condition in every part.

As every unit of surface of the object-glass forms an image at the focus, the superimposed images will be of the same nature and the primary images formed by a large object-glass or a small one, will be of the same quality.

Under this conception the disturbance in definition will depend on the magnifying power, and will be entirely independent of the size of the object-glass. This conclusion appears to be borne out by experience. When the definition is bad, reducing the aperture of the 18½ inch refractor of the Dearborn Observatory, does not materially improve the seeing, and I long ago abandoned the use of caps for this purpose.

A good deal has been written regarding the advantages of a small aperture under the condition of imperfect definition. The following considerations I think will show the fallacy of the argument.

If on a night when the definition near the zenith is at its best, and the highest power (925) of the 18½-inch refractor can be used on a double star of 0".2 or planetary detail studied with a power of 500, the telescope be pointed at a zenith distance of 45°, it will be seen that the definition is not as good as near the zenith. When it is pointed at 60° zenith distance, a lower magnifying power must be used to secure reasonable definition.

When we have gotten below 70° zenith distance one may do some useful work by employing a lower power, but as we approach the horizon a point will be reached where the definition is too poor for any useful work.

A 6-inch object-glass would be affected in the same manner, but objects below a zenith distance of 60°, where the definition was bad, which were observed with the 18½-inch, would be entirely beyond the reach of the 6-inch.[1]

On nights when the definition is bad near the zenith, the 18½-inch can be used on objects which are beyond the reach of much smaller instruments.

Hence, under any atmospheric conditions we can see more and better with a large telescope than with a small one.

The time during which a large aperture can be used to its full capacity is another question.

At Chicago and Evanston the 18½-inch can be used successfully with the highest power on about 10 per cent. of the observing nights. For 50 per cent. of the time it can be used for observations beyond the reach of much smaller instruments, and in the worst condition of seeing it would not be inferior to a smaller telescope.

G. W. HOUGH.

ON THE SPECTRA OF STARS OF SECCHI'S FOURTH TYPE.

An investigation of the spectra of stars of Secchi's fourth type, upon which I have been engaged, with the assistance of Mr. F. Ellerman, since the beginning of the present year, while still in its preliminary stages, has advanced far enough to yield some interesting results. The spectra of 22 stars of this class, ranging in magnitude from 5.4 to 8.2,

[1] *Vide* Catalogues of double stars discovered with large apertures.

have been photographed with the stellar spectrograph attached to the 40-inch refractor of the Yerkes Observatory. In most cases, on account of the faintness of the stars, a dispersion of one 60° prism has been used, but good photographs of the spectra of 132 and 152 Schjellerup have been obtained with three 60° prisms. The work has been confined for the most part to the region between D and *b*, where Cramer's Instantaneous Isochromatic plates have given very satisfactory results. Some photographs of the upper part of the spectrum, extending as far as λ 4450 have also been secured, and by the aid of the new "Erythro" plates the spectrum of 152 Schjellerup has been photographed in the region extending from D to H α.

After a study of the photographs I have been led to the conclusion that the spectra of 152 Schjellerup and other stars of this class contain bright lines, in addition to the heavy bands attributed to some form of carbon and numerous dark lines. On account of Dunér's emphatically expressed disbelief in the existence of bright lines in these stars,[1] I have taken special pains to submit the question to a careful test. The true character of these lines seems to me to be demonstrated by the following considerations:

1. The lines are best shown on photographs taken with high dispersion (3 prisms); whereas bright spaces between dark lines would be most conspicuous with low dispersion. This photographic result is confirmed by visual observations made with the 40-inch telescope. With a small direct vision spectroscope the bright lines cannot be seen, but with a dispersion of three prisms the brightest ones have been observed without difficulty in 132 and 152 Schjellerup.

2. Widening the slit does not cause them to disappear, nor, in the case of such lines as λ 5593, does it appreciably diminish the visibility.

3. The intensity of many of the bright lines in the photographs is decidedly greater than that of any part of the spectrum in their vicinity which appears to be continuous.

4. At my request the spectrum of 152 Schjellerup has been observed by Professors Keeler and Campbell with a three-prism spectroscope attached to the 36-inch Lick telescope. Professor Keeler reports that in his opinion "there is little doubt that the spectrum of this star contains bright lines."

The wave-lengths of about one hundred bright and dark lines between *b* and D in the spectrum of 152 Schjellerup have been deter-

[1] *Sur les Etoiles à spectres de la Troisième Classe*, p. 10.

mined from measurements made on several plates. It is perhaps worthy of note that the mean wave-lengths obtained for two of the most intense bright lines, λ 5592.8 and λ 5693.4, agree very closely with the mean wave-lengths of two bright lines in the spectra of the Wolf-Rayet stars, Professor Campbell's values being λ 5593 and λ 5693. Although several other bright lines in fourth type spectra probably fall very close to Wolf-Rayet lines, it is too soon to conclude that these classes of stars are related. With this possibility in mind, however, I requested Mr. J. A. Parkhurst, who had kindly offered his services, to determine the distribution of fourth type stars with reference to the Milky Way. The results of Mr. Parkhurst's investigations indicate that stars having spectra of the fourth type exhibit a decidedly greater tendency to cluster in and near the Milky Way than any other class of stars except those of the Wolf-Rayet type.

A comparison of fourth type (III *b*) spectra with those of the third type (III *a*)[1] fails to show any very striking similarities, though there appear to be certain resemblances, particularly in the region just below *b*, which deserve and will receive further study.

The peculiarities in the spectra of the stars 541 Birmingham (*DM* 38° 3957) and *DM* 59° 2810, which were recognized and discussed by Professor Dunér,[2] are well brought out in the photographs. It has been found possible to arrange the spectra of ten stars in a series, having at one end 155 *b* Schjellerup and at the other *DM* 59° 2810. The differences between contiguous spectra are in most cases very slight, though 541 Birmingham, which comes next to *DM* 59° 2810, is separated by a rather wide gap from the star next above it. 132 Schjellerup comes near the middle of this series. I have as yet no evidence favoring Dunér's hypothesis that fourth type (III *b*) stars are developed from those of the second class (II *a*).

The investigations will be continued as rapidly as possible, but it is necessarily slow, as the 40-inch telescope is available for this work on but one and one-half nights each week, and for the fainter stars exposures of many hours are required. Mr. F. Ellerman has had an important part in the work, as he has made many of the photographs and rendered assistance in the work of reduction. For the last few weeks I have also had the aid of Dr. Frank Schlesinger, Research Assistant

[1] Photographs of the spectra of many stars of the third type were taken for this purpose.

[2] In his invaluable memoir *Sur les Étoiles à spectres de la Troisième Classe.*

during the Summer Quarter, who has done excellent work in measurring photographs and determining wave-lengths.

GEORGE E. HALE.

PORTRAIT-LENS PHOTOGRAPHS.

While connected with the Lick Observatory series of photographs were made of the Milky Way, the various comets, etc., with a six-inch portrait lens. Lantern slides from these pictures were projected on the screen. Some of the subjects were:

The phenomenon of the "old Moon in the new Moon's arms," or the Earth-lit portion of the new Moon. The night part of the Moon, illuminated only by light reflected from the Earth, was clearly shown on the photograph and the details of the lunar surface during the lunar night could be made out distinctly.

The total eclipse of the Moon September 3, 1895. These photographs were made in the hope of showing a possible lunar satellite which might at the time be outside the shadow and fully illuminated.

The photography of meteors. It was found that meteors were rather frequently caught with the photographic plate and the short focus portrait lens. Several photographs of meteor trails were shown which had been obtained at the Lick and Yerkes Observatories.

Photographs of numerous portions of the Milky Way were exhibited showing the cloud structures and the great dark rifts where the substratum of stars seemed to be breaking up. A photograph in the region of Antares seemed to show that the apparently small stars that made up the ground work of the Milky Way in this region were really comparatively small bodies, perhaps very much less then our own Sun in size.

The various comets had been photographed and many extraordinary phenomena, heretofore unknown, were shown on the pictures, some of which were highly suggestive.

The peculiar phenomena shown in the tail of Swift's comet of 1892 could readily be explained by an irregular emission of matter from the nucleus, while the photographs of Brooks' comet of 1893 showed such an extraordinary condition of the tail that some outside influence seemed required to explain the phenomena. It was suggested that the tail of this comet possibly encountered some kind of resisting medium about October 21, 1893, and for some time subsequent to that date. No other explanation seemed satisfactory.

E. E. BARNARD.

A BRIEF ACCOUNT OF THE WORK OF THE BLUE HILL METEOROLOGICAL OBSERVATORY.

Although in the past meteorological observatories have been associated generally with astronomical institutions, yet this union usually is disadvantageous to the former, and the separation is now customary, especially in Europe. In the case of the Harvard and Blue Hill Observatories the circumstances favoring coöperation were exceptional. The former maintained meteorological observations in some detail, while the latter, only twelve miles distant, was admirably located and equipped for this work, which, moreover, it was desired to continue indefinitely and to publish in a permanent series. Accordingly an alliance was formed in 1887, two years after the foundation of the Blue Hill Meteorological Observatory by the writer, whereby his observations and investigations are published annually, or oftener, in the *Annals of the Astronomical Observatory of Harvard College*, at the joint expense of the college and the writer. It is expected that the two institutions will be united ultimately, and with this expectation the summit of the hill on which the Blue Hill Observatory stands has been leased for a long term of years to Harvard College. The writer, however, continues to direct the work at Blue Hill and to defray the whole cost of maintenance. Three assistants are now employed, and the annual expense exceeds $4000.

The Blue Hill Observatory was probably the first in this country to record automatically and continuously all the meteorological elements, of which hourly values have been reduced, printed, and discussed. Local weather predictions were issued for several years until the United States Weather Bureau commenced this service in Boston in 1891. Of various investigations undertaken and published, there may be mentioned the comparison of different forms of anemometers by Mr. Fergusson; the first measurements in America of the heights and velocities of clouds by Messrs. Clayton and Fergusson in 1890–1; and the exploration of the air by means of kites, which was originated at Blue Hill in 1894. An exhaustive discussion by Mr. Clayton of all cloud observations has been published, and the international cloud measurements which were completed last year will soon be printed. At the present time the chief work, apart from the routine observations, is obtaining simultaneous records of the temperature and relative humidity of the air and the velocity of the wind at heights exceeding two miles in the free air by means of kites and near the ground. It is expected that

the final discussion of the kite records will be published by the Smithsonian Institution, which has aided the investigation by a grant from the Hodgkins Fund.

A. Lawrence Rotch.

PHOTOGRAPHIC RESEARCHES NEAR THE POLE OF THE HEAVENS.

If a series of short exposures be made with a photographic telescope pointed at the pole of the heavens, we obtain a negative on which each star gives a series of dots lying approximately in a circular arc corresponding to the diurnal motion. The common center of all such arcs will be the point on the negative representing the pole on the sky. It is evident that photographs of this kind furnish a method of determining the place of the pole with respect to the surrounding stars at the time the negative was made. Moreover, by the intercomparison of the results obtainable from plates made on different dates, it is possible to arrive at a determination of the fundamental constants of stellar astronomy.

The method possesses the advantage of being entirely different in principle from those hitherto in use, and as it promises high precision, it may serve to obtain a useful check upon existing results. The first attempts to use the method practically were made, I believe, at the Harvard College Observatory, by Professor E. C. Pickering, some years ago. The present paper contains, however, the first approximately complete discussion of exact measurements upon plates of this kind. The negatives employed were made at Helsingfors by Professor Anders Donner for the writer. The Observatory of Helsingfors possesses the advantage of being the most northerly of existing observatories provided with adequate photographic telescopes. Photographs of the pole made at Helsingfors are therefore less distorted by refraction than those made elsewhere on account of the greater altitude of the pole at that place. The elimination of refraction effects by computation constitutes one of the greatest difficulties with which the writer has had to contend, so that the importance of a high latitude for researches of this kind is very evident.

The results here presented consist of:

1. The deduction of formulæ suitable for the complete reduction of ordinary polar star photographs, as well as the special kind of plates just described.

2. An application of the formulæ to measures on one plate of six images of each of ten stars, or sixty images in all.

While no entirely definite conclusions can be drawn from material so scanty, enough has been done to show that the new method merits the serious consideration of astronomers. It is the intention of the Columbia Observatory to extend the work so as to include the complete measurement of all the images on two Helsingfors plates made six months apart. A tentative determination of the constant of aberration should thus be possible, and should throw much light on the possibilities of the new method. The details of the work so far accomplished cannot be summarized in this brief notice, but an extended paper is in the hands of the printer, and will, it is hoped, soon be laid before the astronomers.

HAROLD JACOBY.

A PROPOSED CATALOGUE OF NORTH POLAR DISTANCES.

The United States Coast and Geodetic Survey has made it its uniform practice to make careful computations of the mean north polar distances of all stars observed for latitude with a zenith telescope. It is now proposed to publish in the near future the accumulated results of these years of computation in the form of a star catalogue.

The catalogue will comprise about 3500 stars, all brighter than the seventh magnitude. The computations have been made substantially upon the Boss system — the weights and systematic corrections of that system as published in the Northern Boundary Report being used for the catalogues there given and supplemented by special investigations for later catalogues.

In most of the later computations both the polar distance and proper motion have been derived by the method of least squares and the probable error of each will be given in the catalogue.

J. F. HAYFORD.

THE K LINES OF β AURIGAE.

By Antonia C. Maury. (Published in the ASTROPHYSICAL JOURNAL, October 1898.)

THE VARIABLE STAR U PEGASI.

By G. W. Myers. (Published in the ASTROPHYSICAL JOURNAL, October 1898.)

THE ZODIACAL LIGHT.

Fifty years ago, and indeed until within ten or twelve years of the present time, all hypotheses relating to the origin of the zodiacal light were opposed by difficulties which could not satisfactorily be met. The recent progress of our knowledge upon the subject consists chiefly in the removal of the difficulties attending one hypothesis — that which assumes the light to be reflected from meteoric dust forming a part of the solar system. At present, therefore, this hypothesis tends more and more to prevail. It is true that the two principal observers of the zodiacal light, Jones and Heis, were inclined to regard it as a ring encircling the Earth. The obvious objections to this hypothesis are the considerable extent of the light in latitude, which would require the supposed ring to be very near us, and the absence, at the same time, of any decided parallax, or of any obscuration by the shadow of the Earth. The hypothesis, apparently, was suggested by the observations which tended to show that the zodiacal light forms a continuous belt all along the zodiac, with a slight maximum of brightness, commonly called the Gegenschein, in opposition to the Sun. This maximum was the chief difficulty in the way of the meteoric hypothesis now prevalent, for, according to Lambert's theory of phases, which had acquired a fictitious authority by long usage, no such maximum should exist. But accurate photometric observation of asteroids in recent times has made it clear that Lambert's theory is wholly inapplicable to their phases, and if we suppose that meteors have phases like those of asteroids, it appears that light reflected from such bodies should exhibit a maximum at opposition.

Since the time of Jones and Heis, observation of the zodiacal light, in its ordinary and conspicuous form, has been greatly neglected. On the other hand, we have numerous recent observations of Gegenschein, and some which were undertaken in 1893, to be made as nearly as possible simultaneously at widely separated stations, formed a principal subject of the paper of which this is an abstract. It was concluded from the comparison of nearly simultaneous observations made in New England, in California, and in Peru, that no effect of parallax in the observed object could be detected.

Another subject of the paper was the bands permanently visible in and near the zodiac, and probably due to aggregations of faint stars or of nebulous matter, which tend to interfere with exact observation of

the fainter portions of the zodiacal light, including the Gegenschein. Simultaneous and careful drawings of these bands were made by two observers during 1893 and 1895, and plates showing specimens of these drawings were laid before the audience. It appeared from these plates that the agreement between the two observers was sufficient to encourage the belief that the drawings represent real objects, which should be carefully studied by all those who desire to add to our knowledge with regard to the zodiacal light.

ARTHUR SEARLE.

ROTATION OF ASTEROIDS.

The suggestion that if the asteroids were observed photometrically there might be a discrepancy arising from a difference in the reflection from the opposite sides of an asteroid, presented to us at different times in consequence of their rotation, did not originate with me. Prior to my observations discrepancies in the observations had been attributed to this cause as a probable explanation. In the first year of my observation of asteroids, 1887, I found discrepant observations of two asteroids, Nos. 40 and 42, which seemed to me to indicate their probable rotation. There were twelve asteroids more fully observed which showed no such difference. In the following year, 1888, I observed No. 40 much more thoroughly and demonstrated to my satisfaction that no such variation as I had suspected existed in its light. During 1888 and 1889, the number of asteroids which I observed was more than doubled, and no additional asteroid was suspected of such variation. It has not been practicable for me to take up the remaining asteroid, No. 42, until June of the present year. I have now observed it anew, with the result that no such variation appears. Furthermore, upon revising the observations of No. 42 in 1887, by the aid of the constants obtained from the more extended observations of the present year, the hypothesis of rotation is contradicted by those very observations of 1887.

Of course I cannot prove a negative; it is not impossible that some asteroid does exist, observation of which would show large variation from rotation; but all my evidence having been demonstrated to be illusive, and the observation of many new asteroids not yet furnishing additional evidence of it, I think it is safe to dismiss the theory of a photometric change from rotation from further consideration.

HENRY M. PARKHURST.

REMARKS REGARDING THE PARALLAXES OF 61^1 AND 61^2 CYGNI AND THE PROBABLE PHYSICAL CONNECTION OF THESE TWO STARS.

In *Contribution 13* from the Observatory of Columbia University a discussion of the measures of certain photographic plates, made by Dr. Rutherfurd in 1871–1874 for the determination of the parallax 61 Cygni, has been presented by the writer, to whom the measures were entrusted for that purpose by Professor J. K. Rees, Director of the Observatory.

The main result given in that publication is summarized by the lines:

$$\text{Parallax of } 61^1 \text{ Cygni} = +0''.360 \pm 0''.015.$$
$$\text{Parallax of } 61^2 \text{ Cygni} = + \quad .288 \pm \quad .028.$$

The object of the paper prepared for the Astronomical Conference was to suggest what these results signify.

In the first place, consideration was made of whether these two stars are only optically double or are physically connected, forming a binary system. This is a question which has adherents on each side, some claiming that the variations of measures of distance, from Piazzi's time to the present, show an orbital motion; others claiming that such variations are due to accidental or systematic errors of observation. But it was pointed out that the theory of probabilities has been used somewhat more effectively in favor of orbital motion than has been the better established theory of motion of matter acted on by gravitation. Thus, too often, have the claimants of rectilinear motion been met by the statement that whether the *measures* are conclusive or not, the *chances* are many millions to one against two stars of such unusual proper motion being placed accidentally in such close juxtaposition in line of sight from the Earth at this particular age in the Earth's history.

Then were quoted the conclusions arrived at by Wilhelm Struve regarding the probability of their binary character. The "reasoning in a circle" by Otto Struve from the conclusion of his father back to his hypothesis was used to show that beliefs regarding this matter are based sometimes more on tradition than on logic. And the Spittaler and Zona comets of 1893 were instanced (by the quoting of Professor Barnard in *Sidereal Messenger*, **10**, 18) to show how facts sometimes overrule probabilities. Other arguments were also adduced for the purpose of removing many of the traditional beliefs now existing concerning these stars.

While facts are more convincing than probabilities, so also are measures as convincing as logic. It was interesting, therefore, to note that the measures made by Professor Wilsing at Potsdam as discussed by the writer likewise seem to confirm the results deduced from the Rutherfurd plates. This new discussion, given in *Contribution 13*, shows a difference of parallax:

$$(61^1 \text{ Cygni} - 61^2 \text{ Cygni}) = +0''.088 \pm 0''.012.$$

The mean of previous determinations of the parallax of each of these stars give also a difference of:

$$(61^1 \text{ Cygni} - 61^2 \text{ Cygni}) = +0''.082 \pm 0''.013.$$

While admitting, therefore, the great need of further observations, and not denying the possibility of Professor Wilsing's hypothesis that 61^1 Cygni may have a dark companion, it seems that the evidence at present available leaves little room for doubt as to the existence of the difference of parallax detected by the measures of the Rutherfurd plates. And since it is the well-accepted policy of scientific investigators to accept provisionally as true, until disproved (if such should be its ultimate fate), that which has the greatest direct evidence in its favor, we are called on to believe that the two stars of 61 Cygni are too remote from each other to form a binary system. But it is much to be desired that more evidence shall be accumulated to either verify or disprove this conclusion, and thereby throw more light upon the mystery of these interesting, because troublesome, stars.

HERMAN S. DAVIS.

THE PROBABLE RANGE OF TEMPERATURE ON THE MOON.

By Frank W. Very. (See p. 199.)

THE DOUBLE STAR WORK OF THE FLOWER OBSERVATORY, UNIVERSITY OF PENNSYLVANIA.

The object of this communication is to call attention to the performance of the 18-inch equatorial of this Observatory. While there are in this country a number of larger instruments by Alvan Clark & Sons this is the largest so far attempted by Brashear.

The atmospheric conditions probably differ little from those at other points east of the Allegheny Mountains. The diffraction rings are not often seen, in fact on only one occasion has an entirely satisfactory view of these been had. They were then clearly defined and

symmetrically arranged, showing that their customary absence is due to no fault of the glass.

The list of stars observed has been arranged by Mr. Burnham, and included a considerable number of difficult objects.

First will be mentioned very close pairs, not very unequal in magnitude, furnishing a test of the separating power; this, for an aperture of 18 inches, is $0''.275$ by Dawes' formula. A small list of stars of distance $0''.5$ and less follows. These have all been clearly separated and measured.

Star	α	δ	ρ	θ	Mags.	Remarks
β 232	$0^h\ 43^m\ 38^s$	49° 59′	$0''.30$	326°	8–8	
A. C. 13	1 1 59	44 34	0 .35	250	8–8	
β 1017	6 6 28	— 2 56	0 .50	160	8–9	
O Σ 234	11 25 24	41 50	0 .30	140	7–8	
O Σ 269	13 28 18	35 46	0 .35	224	7.3–7.7	
β 939	14 7 48	— 7 58	0 .50	146	8–8	
β 1879	14 40 23	10 10	0 .50	145	8–9	
O Σ 285	14 41 42	42 48	0 .30	130	7.5–7.6	
η Cor. Bor.	15 19 6	30 39	0 .44	327	6–6	
Δ 15	16 40 12	43 42	0 .40	340	8–8	
β 814	16 23 9	40 9	0 .24	320	8+–8+	
β 631	17 33 47	— 0 35	0 .40	60	7–7	
O Σ 337	17 44 46	7 16	0 .40	32	7–8	
β 671	20 29 34	62 3	0 .50	330	8–10	(Unequal.)
β 155	20 47 25	50 38	0 .50	37	7½–8	

Second — Close, faint companions to bright stars. These afford a test of the condition of the atmosphere rather than of the telescope. Usually the blurring of the bright star renders a critical test of the glass impossible.

Among other pairs of this class the following have been satisfactorily measured:

Star	α	δ	ρ	θ	Mags.	Remarks
O Σ 38	$1^h\ 57^m\ 48^s$	41° 51′	$0''.40$	120°	5½–7	
Σ 1306	8 59 48	67 37	1 .3	210	5–8.2	
O Σ 235	11 26 42	61 38	0 .70	98	6–8	
Σ 1768	13 33 0	36 48	1 .1	133	5–8½	
β 616	14 27 15	38 50	28 .	100	4–12	
μ^2 Boötis	15 20 42	37 43	0 .85	80	6½–8	
β 1251	17 36 55	16 2	1 .2	70	5.8–10	
β 954	16 50 59	18 38	2 .5	178	5–12	
β 151	20 32 54	14 15	0 .7	359	4–6	
β 733	23 56 54	26 34	0 .7	223	6–10	

Third — Excessively faint stars. Among Burnham's measures with the 18½-inch Clark glass of the Dearborn Observatory are found a number of stars marked 16–14 magnitude. The note "excessively faint" accompanies most of these. In one case is a star whose magnitude is given as 14 which was not measured at all (β 639).

In case of all these pairs where the attempt has been made, including the last mentioned, it has been found practicable to obtain satisfactory measurements.

The measurements at the Flower Observatory were all made by Mr. Eric Doolittle, who has had no previous experience in this class of work. Yet he has been able to see and measure objects as faint as those which so experienced and skillful an observer as Mr. Burnham could reach with the slightly larger Dearborn glass.

No effort has been made to find new pairs, but a number have been picked up in connection with the regular work.

The following are believed to be new:

Star	α	δ	ρ	θ	Mags.	Remarks
1	$0^h\ 4^m\ 33^s$	57° 8′	1″	285°	9.8–10.5	Near K1
2	6 10 6	— 4 52	4½	243	6 –11	
3	6 50	56 42	4	328	9.5–10	
4	8 40	56 38	6½	120	9 –11.5	$\overline{AB}$
			40	242	12	$\overline{AC}$
5	9 43	58 45	1.8	37	9 – 9.4	
Σ1775	13 37 18	— 3 40	39	178.5	13.5	$\overline{AC}$
β33	15 24 42	—12 35	32	132	11.5	$\overline{AE}$
8	21 23	59 34	7	115	9 – 9.5	
9	21 31	59 11	2	127	8.5 – 8.8	
10	21 33	58 22	10	162	9.5–10	
11	21 37	57 43	3	40	9 –11.5	
12	22 26 30	55 49	3	330	10.8–11	
13	22 27 30	56 21	1.4	45	9½–10½	
14	22 28 30	56 31	3	235	9.8–11	

We expect soon to publish the observations made during the past eighteen months, embracing about 500 pairs.

C. L. DOOLITTLE.

THE POSITION OF THE AREQUIPA STATION OF THE HARVARD COLLEGE OBSERVATORY.

During a temporary residence at Arequipa, through the kindness of Professor Pickering and of Professor and Mrs. Bailey, the latitude and longitude of the station were determined. The chief instrument avail-

able was the special transit instrument devised for use in the prime vertical by the late Professor W. A. Rogers and described at the meeting of the A. A. A. S. in 1892. This instrument could not be adapted to use as a zenith telescope, but proved a very excellent instrument in the prime vertical. Two of Bessel's methods were employed, and the result is

$$\phi = -16^\circ\ 22'\ 28.''0 \pm 0''.19.$$

The longitude was obtained by telegraph with a temporary station at Arica, Chile, whose longitude had been determined by officers of the United States Navy in 1883. Their determination of the longitude of Arica was part of an extensive series of longitudes on the west coast of South America through the coast cables. Considerable difficulty was found in getting telegraphic connection between Arequipa and Arica, though there is a land line between the places, which, however, is never used for through messages. It became necessary to use the land line to the seaport Mollendo and to repeat the signal by cable between Mollendo and Arica. Communication was made in this way on seven nights, and proper precautions taken to insure the elimination of the errors of transmission. The result is

$$\Delta\lambda, \text{ Arequipa} - \text{Arica}, +4^m\ 51^s.81 \pm 0^s.032.$$

Assuming the longitude of Arica to be $4^h\ 41^m\ 19^s.90$ the longitude is

$$4^h\ 46^m\ 11^s.71 \text{ W. of Greenwich.}$$

WINSLOW UPTON.

RECENT BOLOGRAPHIC RESULTS FROM THE ASTROPHYSICAL OBSERVATORY AT WASHINGTON.

In his absence Secretary Langley authorizes me to state, on behalf of the Astrophysical Observatory at Washington, something with reference to the recent results derived at that Observatory in the bolographic investigation of the infra-red solar spectrum.

By the use of the bolographic method devised by Dr. Langley and developed at this Observatory there have now been found over 700 absorption lines in the solar spectrum between wave-lengths $0^\mu.76$ and $6^\mu.0$. Of these more than two-thirds have been added in the last eight months, owing to the use of several new pieces of apparatus lately obtained.

It will be recalled that this method essentially consists in the auto-

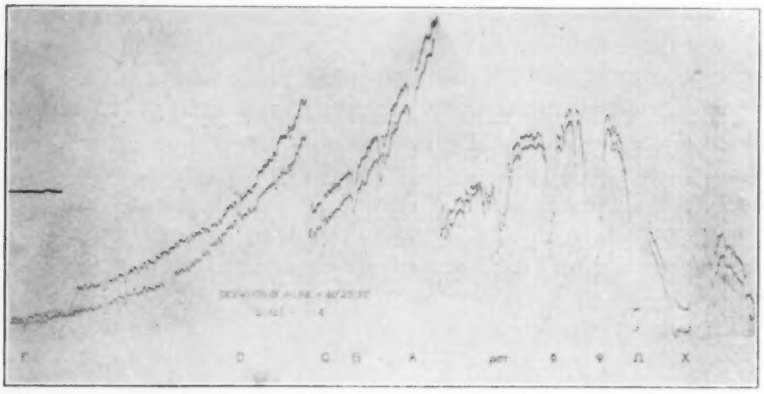
matic production of an energy curve, in which abscissæ correspond to prismatic deviations and ordinates to energy of radiation in the spectrum. Indentations in this curve indicate diminution of energy due to absorption, either from the Sun's gaseous envelope or our atmosphere, and thus give the position of Fraunhofer lines.

It will be readily understood that attention must be paid to exclude errors from the introduction of deflections due to tremor of the ground, fluctuations of the electric current, and to other causes. These are in practice reduced to the smallest possible magnitudes, and such as remain (being variable in place and form) are eliminated from the final results through a comparison and measurement of six or more plates. Such a reduction as this is very arduous, and, in the case of the present results, has entailed about 44,000 separate comparator observations. The accuracy of the mechanical devices by which the abscissæ of the bolographs are governed is extreme, and it is largely due to this that the final values of deviation are not usually in error (in so far as dependent on the bolographic processes) by as much as a second of arc.

The abscissæ of the bolographs, giving as they do the accurate position of the absorption lines, are naturally of the first importance in the present work ; but the ordinates, corresponding to intensity of radiant energy, are by no means lost sight of. Indeed, at several regions in the infra-red spectrum there have lately been noticed very marked changes in the absorption. It appears, for instance, that for three months in the year, which are (fortuitously or otherwise) the months in which foliage is put forth, there is a very noticeable decrease in the absorption on the long wave-length side of the band at about $1^{\mu}.4$ called here ψ. Paschen has found this band to be caused by water vapor. If the absorption in the portion affected was due to carbonic acid gas perhaps the phenomenon might be accounted for by the vegetable growth as above hinted.

To illustrate the general form of the energy curve, as well as the agreement between successive bolographs, two superposed curves extending from the F line in the green to the great absorption band Y at about $4^{\mu}.2$ are presented in the accompanying plate. These curves are given on a background of plotting paper whose intervals (reduced in the same ratio as the curves) were originally centimeters, and correspond each to $4'$ of arc in deviation. At one point between F and D one curve was intentionally shifted in the making, as it was

feared to be too near the edge of the photographic plate. The scale of ordinates was altered at three points by changing the slit width. From F to near C it is 1.00; from this point to below A it is 0.50; from



this point to X it is 0.20, and from this point to the close, 1.00. Such curves as these show in the original some 200 "real" deflections. In detail work the scale of deviations is spread out four times, the plate is moved much slower, and as a consequence, many small deflections here rushed over and obliterated are brought out.

C. G. Abbot.

THE DISTORTION OF PHOTOGRAPHS MADE WITH THE BRUCE 24-INCH PHOTOGRAPHIC TELESCOPE.

A letter was read from Professor H. H. Turner, University Observatory, Oxford, England, giving the provisional results of measurements of a plate taken with the Bruce 24-inch photographic telescope in order to determine the distortion, if any. His conclusions are:

"First—The optical distortion on the plate is quite small, if existent, up to 3° from the center, and perhaps further; that is, the star images are truly projected on a tangent plane with considerable exactness. I have not yet detected any *radial* displacement, though there seems to be a small term depending on the product *xy* indicating a sort of *strain* of the field.

"Second—Whatever may be the ultimate definite result as regards optical distortion, your plates will give (by due allowance for such distortion which will be quite easy) as good places as we are getting on

the plates for the Astrophotographic Catalogue. The images are perhaps a little larger and more diffused, but are quite easy to measure. This holds for certainly $4^\circ \times 4^\circ$ and probably further.

"Third — If I am right in believing that fear of optical distortion was the motive for rejecting the photographic doublet, the above conclusions show this fear to have been groundless, and the manifest advantages of getting a large field at once prove the doublet to be the right instrument — certainly for charting purposes."

ON A PRACTICAL METHOD OF PHOTOGRAPHING THE SPECTRUM OF THE CORONA IN NUMEROUS DISTINCT REGIONS.

RECENT research on the corona indicates that it is a composite of a triple system of rays or streamers. But it is not known whether the filaments of these systems have the same origin or not. Perhaps the only conclusive method of testing this important question is that of a multiple spectroscope, in which slits are arranged tangentially at both extremities of equatorial and polar diameters; also radially, or approximately so, along the lines of expected streamers. It is proposed to bring the spectra of at least four separate inner coronal regions on a single plate, and of four outer areas on another plate. All on a given plate will therefore have the same exposure and development, and will be approximately comparable. A two-inch image with large aperture will be requisite; and the varying lengths of exposure, together with a maximum number of plates, are easily secured by means of the automatic apparatus of the Japan expedition of 1896.

DAVID P. TODD.

ON AN EFFECTIVE INSULATION OF MERCURIAL HORIZONS.

In regions of frequent and violent seismic disturbance, like Japan, it is well known that shocks which are very destructive at lower levels on the plains, may often fail to be felt in the mountains surrounding them. The reason for this is not difficult to see: as the origin of the earthquake wave is submarine, the vibrations, which readily propagate themselves through the relatively small masses of earth in the plain, become dissipated by inertia of the vaster masses of outlying mountains. Application of this principle to the insulation of a support for a mercurial horizon has led to complete success in checking the tiny undulations of its surface which destroy its capacity for specular reflection. First a zenith collimator of the ordinary type was constructed, in

which the reflected reticle was perfectly visible in a collimating eyepiece. Then several slabs of marble or granite, about three inches thick and a yard square were provided; the number requisite will vary with the degree of disturbance to be overcome, and the perfection of insulation sought. Practically, five or six will be sufficient. They are laid up horizontally, as in strata, but separated from each other by wave-checking material, inserted at three points between each two slabs. Practically, tufts of any material suitable for the ordinary mattress serve this purpose well; but I have obtained the best results by the use of cork-dust in small, tightly-stuffed bags. The top slab of the series is made three or four times the thickness of the intermediate ones, and surmounted on this is the zenith collimator. Of course the slightest touch of the finger to the topmost slab will cause the reflected reticle to disappear; but a nadir observation is wholly secure against interruption by passing freight trains and trolley cars, although in close proximity.

DAVID P. TODD.

ON THE FOUNDING OF ASTRONOMICAL AND OTHER INSTRUMENTS OF PRECISION.

All astronomical and physical instruments work best when provided with (1) an absolutely stable foundation, and (2) a perfectly rigid mounting. These ideal conditions can only be reached approximately. In my experience the first is more often secured than the second. The object of this paper is to show how rigidity of mounting may be secured equally with stability of foundation. This means, of course, a welding or union of foundation and mounting into one. If it is convenient or practicable to build the mounting very massive, gravity alone may make this union sufficiently effective, provided ordinary care is exercised in making the junction at three points only. But in many classes of instruments, massiveness of mounting is wholly impracticable. Eclipse instruments especially belong to this category; they must be light in order to be easy of transportation, but rigidity is equally essential for perfect definition of photographs of the solar corona. As a result of several years' study of this problem, in connection with preparation for several expeditions, I have finally reached a satisfactory construction for effecting a union of mounting and foundation, which appears applicable to instruments in observatories as well. Simply stated, it is a method by which the mounting is enabled to secure a

permanent grasp upon many tons of earth underneath it. First, three holes were dug, as if for setting the posts of a fence; their distance apart is regulated by the area desirable to include as the base of the instrument. Into these holes were set three wrought-iron pipes, about five feet long and three inches in diameter; perhaps two feet of each pipe being left projecting above the surface of the ground. To the bottom of each pipe was screwed a projecting flange, and the hole around both pipe and flange was filled about a foot deep with cement and gravel, thoroughly rammed into position and allowed to harden. The remainder of the holes were then filled as was most convenient. The second point of construction was met by placing three stout timbers or pipes horizontally between the vertical pillars. These were forced into position close to the ground, and spread the pier pipes a trifle outward. Through holes bored near the top of the pier pipes, long rods or bolts were then run, parallel to the timbers below them, thus forming the third essential of the mechanical construction. By tightening up these bolts in the ordinary way, the tendency was to spread the cement bases of the piers outward. But these would yield only slightly, and any degree of tension could be secured by means of the bolts. All these features are shown in the accompanying plate. This highly portable form of mounting was devised and first employed for three mountings for the photographic instruments of the Amherst Eclipse Expedition of 1896, equipped by the liberality of Mr. D. Willis James, of New York, and sent out to Japan in his yacht "Coronet." Such a mounting admits of the most rapid installation, and furnishes a degree of rigidity unusual in the ordinary types.

DAVID P. TODD.

RESULTS OF HELIOMETER OBSERVATIONS ON THE REFRACTION OF RED STARS.

By F. L. Chase.

SWIFT'S COMET (I, 1892).

Professor William H. Pickering presented a paper (not read) on "Swift's Comet, I, 1892." This comet, discovered March 6, was first noticed to have a faint tail, by Finlay, on March 26. As discovered at Arequipa March 29, the tail was well developed. Forty-four photographs were taken of this and used in a recent investigation of its nature. The tail was plainly twofold in character, the inner tail con-

tinuously issuing from the head, and, being at least twenty degrees in length a month after passing perihelion, consisted of two absolutely straight rays inclined at an angle of ten degrees. The outer tail was formed of successive eruptions from the head, later diminishing in angle. The whole effect was to produce multiple tails like the comet of 1744. The photographs showed the inner tail to be of a different character on alternate days, now appearing continuous near the head, and now bifurcated. The explanation is that the comet rotated about a longitudinal axis directed toward the Sun, the rotation period determined being 94.4 hours. This period was determined by the use of the photographs of Professors Barnard and Wolf, and those made at Arequipa by the writer. Bessel observed in Halley's comet, in 1835, "a vibration from side to side," with a period of 110 hours; this was probably a similar rotation of the comet with an analogous period. The changing appearance of both comets being explicable by the hypothesis of rotation, the next endeavor was to find a physical explation of the cause of such rotation. The Sun furnishes a strong electromagnetic field, the comet also, by the electrical induction of the Sun, receives electrical charges, and these charges are, by the gases of the tail, radially projected from the head of the comet, and become in effect so many electrical currents. The result of the motion of these radiating currents, *i. e.*, tails in the magnetic field of the Sun, is the production of a spinning of the comet about a longitudinal axis. Theory would thus produce the rotation demanded by observation, and the rotation would be independent of the direction of the motion of the comet, but north of the solar equator the rotational force is in one direction, and south of it in the other.

It is generally impossible to indicate a point in the tail of the comet; the exception occurs in the plates of April 6, 7, 8, and 10, where a bright detailed structure is receding with increasing velocity of from one million to 25 million kilometers per day. The velocity of recession is thirty-six times the acceleration of gravity, and does not agree with any of the velocities required by Bredichin's hypothesis. The spectrum as given by the objective prism, of the head and the tail, showed five bands probably due to hydrocarbons. A further test of the theory of axial rotation of comets near the Sun would be an observed change of direction or speed of rotation in the solar magnetic field. Another would be the observation of the rotation when the tail is directed approximately toward the observer.

VARIABLE STARS IN CLUSTERS.[1]

THE discovery, by Professor S. I. Bailey, of the presence of large numbers of variable stars in certain globular clusters has already been announced in Circulars Nos. 2 and 18. A systematic search for such variable stars has been made by Professor Bailey and has led to the results given below. In the following table the first column gives the number in the *New General Catalogue* of Dreyer; the second, the Messier number, or, in certain cases, some other designation; the third and fourth, the position for 1900; the fifth column, the approximate number of stars examined; the sixth, the number of plates used in the examination. In the case of certain clusters later investigations have included more plates. The seventh column gives the area, always a circle having for its center the center of the cluster, included in the examination. The eighth column gives the number of variable stars found; the ninth, the maximum distance of any variable from the center of the cluster. In *N. G. C.* 7078 this distance is given as 7′, since a circle having a radius of 7′ includes 50 variables. One variable, perhaps not related to the others, is found at a distance of 10′. The tenth column gives the area of a circle of sufficient radius to include all the variables. The eleventh column gives the proportion of variables to the whole number of stars examined; the twelfth, the number of stars to one variable.

As will be seen by reference to the table, the whole number of stars examined is 19,050, of which 509 are variable. This amounts to one variable in 37 stars, or nearly 3 per cent. It does not follow, however, that clusters in general contain more variable stars than occur elsewhere, for, if we except the four clusters, ω Centauri, Messier 3, Messier 5, and Messier 15, which together contain 393 variables, an average of 7 per cent., the remaining 19 clusters have 116 variables among 13,350 stars, or less than 1 per cent. There is a very striking difference between the results obtained in clusters equally rich in stars, as, for example, between Messier 13, the great cluster in Hercules, where an examination of 1000 stars shows two variables, one in 500, and and Messier 3, where among 900 stars, 132 are variable, one in 7. A common plane of revolution, orbital or axial, of the different systems or individuals of star clusters, and the relation of that plane to the line of sight, might provisionally be suggested as a possible explanation.

[1] *Harvard College Observatory Circular* No. 33.

VARIABLE STARS IN CLUSTERS.

Designation		Position, 1900		No. stars examined	No. plates examined	Area examined	No. variables found	Maximum distance	Area of variables	Proportion of variables	No. of stars to one var.
		R. A.	Dec.								
		h. m.	° ′			Sq. Min.		′	Sq. Min.		
104	47 Tucanae	0 19.6	−72 38	2,000	10	1,257	6	6	113	.003	333
362		0 58.9	−71 23	675	10	314	14	9	254	.021	48
869		2 12.0	+56 41	1,050	10	10,800	1	—	—	.001	1050
884		2 15.4	+56 39								
1904	Messier 79	5 20.1	−24 37	200	6	79	5	3.5	38	.025	40
3293		10 29.6	−57 40	724	10	314	0	—	—	.000	—
4755	κ Crucis	12 47.7	−59 48	555	10	314	0	—	—	.000	—
5139	ω Centauri	13 20.8	−46 47	3,000	10	1,257	125	22	1521	.042	24
5272	Messier 3	13 37.6	+28 53	900	10	1,257	132	17	908	.147	7
5904	Messier 5	15 13.5	+ 2 27	900	10	1,257	85	17	908	.094	11
5986		15 39.5	−37 26	289	12	314	1	1.7	—	.003	289
6093	Messier 80	16 11.1	−22 44	145	5	79	2	2.5	20	.014	72
6205	Messier 13	16 38.1	+36 39	1,000	10	177	2	1.3	5	.002	500
6266	Messier 62	16 54.9	−29 58	960	10	218	26	8	201	.027	37
6397		17 32.5	−53 37	487	5	218	2	7.5	177	.004	244
6626	Messier 28	18 18.4	−24 55	900	9	314	9	7	154	.010	100
6656	Messier 22	18 30.3	−23 59	1,550	10	218	16	8	201	.010	97
6723		18 52.8	−36 46	900	6	314	16	4.5	64	.018	56
6752		19 2.0	−60 8	600	8	218	1	4	—	.002	600
6809	Messier 55	19 33.7	−31 10	440	6	218	2	5	79	.005	220
7078	Messier 15	21 25.2	+11 44	900	10	1,257	51	7	154	.057	18
7089	Messier 2	21 28.3	− 1 16	600	10	218	10	4	50	.017	60
7099	Messier 30	21 34.7	−23 38	275	10	218	3	2.5	20	.011	92
				19,050		20,830	509		4,867		

The periods and light curves of several variables in other clusters have been determined, but the study of those in ω Centauri is well advanced. This cluster may be called the finest in the sky. It lies just within the border of the Milky Way. There are no bright stars near. To the naked eye it appears as a hazy star of the fourth magnitude. It has a diameter of about 40′. The brightest individual stars in this region are between the eighth and ninth magnitude. Over 6000 stars have been counted on one of the photographs, and the whole number is much greater. Only about 3000, however, are sufficiently bright and well separated to serve for comparison in the discovery of variables. Of these 3000, 125 are variable. 150 photographs of the cluster have been taken with the 13-inch telescope, and already 10,000 measures have been obtained, about half of which have been made by Miss E. F. Leland.

Although the results are at present provisional, it is not probable that the final results of the discussion will materially alter the conclusions. Of the 106 variables in ω Centauri whose periods have been determined, 98 have periods less than 24^h. The longest period is that of No. 2, 475^d, the shortest that of No. 91, $6^h\ 11^m$. Three have periods less than 7^h. Of the eight having periods of more than 24^h, two have periods between one and two days, two between two and three days, one of 4 days, one of 15 days, one of 150 days, and one of 475 days.

The largest range in variation is about five magnitudes, and no star has been included whose light changes do not amount to half a magnitude.

The light curves of the 98 stars whose periods are less than 24 hours may be divided into four classes. The first is well represented by No. 74. The period of this star is $12^h\ 4^m.3$, and the range in brightness, two magnitudes. Probably the change in brightness is continuous. The increase of light is very rapid, occupying not more than one-fifth of the whole period. In some cases, possibly in this star, the light remains constant for a short time at minimum. In most cases, however, the change in brightness seems to be continuous. The simple type shown by No. 74 is more prevalent in this cluster than any other. There are, nevertheless, several stars, as No. 7, where there is a more or less well marked secondary maximum. The period of this star is $2^d\ 11^h\ 51^m$, and the range in brightness, one and a half magnitudes. The light curve is similar to that of well-known short-period variables,

as δ Cephei and η Aquilae. Another class may be represented by No. 126, in which the range is less than a magnitude, and the times of increase and decrease are about equal. The period is $8^h\ 12^m.3$. No. 24 may perhaps be referred to as a fourth type. The range is about seven-tenths of a magnitude, and the period is $11^h\ 5^m.7$. Apparently about 65 per cent. of the whole period is occupied by the increase of the light. This very slow rate of increase is especially striking from the fact that in many cases in this cluster the increase is extremely rapid, probably not more than 10 per cent. of the whole period. In one case, No. 45, having a period of $14^h\ 8^m$, the rise from minimum to maximum, a change of two magnitudes, takes place in about one hour, and in certain cases, chiefly owing to the necessary duration of a photographic exposure, there is no proof at present that the rise is not much more rapid.

The marked regularity in the period of these stars is worthy of attention. Several have been studied during more than a thousand, and one during more than five thousand periods, without irregularities manifesting themselves.

A few words may be added in regard to the kind of clusters in which variables have been found. Up to the present time they have not been found in any except dense globular clusters, of which Messier 3, Messier 5, and the great cluster in Hercules may be taken as examples. The number of such clusters within the reach of ordinary instruments is not great. Of the clusters given in the table, *N. G. C.* 104, 362, 5139, 5272, 5904, 6093, 6205, 6266, 6626, 7078, and 7089 may be described as highly condensed; 1904, 5986, 6397, 6656, 6723, 6752, 6809 and 7099 as moderately condensed; and 3293 and 4755 as open clusters. 869 and 884, the clusters in the Sword-handle of Perseus, are little more than regions relatively rich in stars.

The first group of 11 highly condensed clusters having a total of 11,980 stars has 462 variables, or one in 26. The second group of 8 moderately condensed clusters has 46 variables among 4741 stars, one in 103. The two open clusters furnished no variables, and the region of three square degrees around *N. G. C.* 869 and 884, only one.

Thus far the only regions which are found to be especially rich in variable stars are condensed clusters, but even here only in relatively few cases. These dense clusters are commonly called globular, and many of them are such. In some cases, however, as ω Centauri, the form is somewhat elliptical.

N. G. C. 6266 is the most striking example of a highly condensed cluster which is irregular in form. This irregularity is intensified in the distribution of the variables. The cluster is much compressed on the south side. For a distance of 1′ from the center the distribution of the stars seems to be about equal, but if a line be drawn east and west through the center, and the stars within 1′ of this line are omitted, there are 214 stars south and 354 stars north, within 4′ of the central line. In this cluster are 26 variables, of which 19 are north of the central line and 7 south. Excluding those within 70″, there are 15 north and only 1 south.

EDWARD C. PICKERING.

September 17, 1898.

WITT'S PLANET D Q.[1]

ONE of the most important astronomical discoveries of recent years is the finding of the planet D Q, by Witt. This object will come nearer to the Earth than any other similar object, except the Moon. Its minimum distance is about 15 million miles, and the corresponding parallax nearly a minute of arc. To determine the photometric brightness of this object, the stars, —6°5567, —6°5579, —6°5600, —6°5608, and —6°5626 were each measured on five nights with the meridian photometer, eight settings being made each night, with the resulting magnitudes, 7.87, 8.65, 8.71, 8.56, and 9.57, respectively. The probable error of these values varies from ±0.020 to ±0.033. The brightness of the stars, —6°5550, —6°5560, and —6°5588 was later determined differentially from these, with the resulting magnitudes 8.80, 9.89, and 8.37. Mr. Wendell compared the planet on six nights by means of the photometer with achromatic prisms attached to the 15-inch equatorial. The number of settings on each night was 48. On September 5 and 6, 1898, it was compared with —6°5626, on September 9 with —6°5608, on September 12 with —6°5579, and on September 13 and 14 with —6°5588. The resulting magnitudes were 12.19, 11.97, 12.10, 12.01, 12.20, 12.29. Mean, 12.13 ±0.04. As the logarithms of the distances of the Sun and Earth, on the mean date, September 10, were 0.2366 and 9.9115, the magnitude when these distances are both unity becomes 11.39.

[1] *Harvard College Observatory Circular* No. 34.

It is not easy to obtain photographs adapted to determining the photographic brightness of this object, owing to its faintness and rapid motion. With a short exposure the image is very faint, and with a long exposure a trail is obtained which cannot be compared with the circular images of adjacent stars. Measures of the photographic brightness have been made by Mrs. Fleming on plates taken with the 8-inch Draper telescope, and having exposures of about 15 minutes. The planet was not far distant from the variable star T Aquarii and was compared with four of its comparison stars whose photometric magnitudes had already been determined. Plates taken on September 6, 12, 13, 13, 13, 13, 14, 17, 20, and 21, 1898, gave the magnitudes 12.78, 12.75, 12.80, 12.85, 12.78, 12.75, 12.75, 12.72, 12.65, and 12.68. Mean, 12.75 $\pm$0.01. Similar measures of two isochromatic plates taken on September 17 and 20 gave the magnitudes 12.80 and 12.61. Mean 12.70, $\pm$0.08. Since the planet is fainter photographically than photometrically, it is probable that its color, like that of the Sun, is redder than an average star.

Several interesting photometric problems present themselves in connection with this object. First, the approximate diameter may be determined by comparison with the brighter asteroids and satellites, assuming that the reflecting power is the same. Secondly, the great variation in the distance of this object from the Earth will afford an excellent test of the law that the light varies inversely as the square of the distance. The existence of an absorbing medium in the solar system will thus be tested. Thirdly, owing to the proximity of this object to the Earth at opposition, its phase angle will vary by a large amount. It will, therefore, afford an excellent test of the law connecting this angle with the variation in brightness, which has been found by two or three observers independently.

NEBULA IN ANDROMEDA.

A comparison of photographs of the Nebula in Andromeda taken with the 8 inch and 11-inch Draper telescopes on September 20 and 21, 1898, with similar photographs taken in 1893, 1894, 1895, and 1896, fails to show the new stellated appearance recently announced by Seraphimoff of Pulkowa. See also *A. N.*, **147**, 223.

EDWARD C. PICKERING.

September 30, 1898.

To the Editors of the ASTROPHYSICAL JOURNAL :

GENTLEMEN : In the ASTROPHYSICAL JOURNAL, Vol. VIII, p. 102, there is an article by Mr. Mitchell on the "Concave Grating," in which I am named as an investigator on the theory of this beautiful apparatus. I beg you to state that I have no merits in this direction. In the *Handbuch der Physik*, I have only published an abstract of some parts of a very complete investigation on the concave grating written by Professor C. Runge, but never published in full. In the *Handbuch* I of course stated that the theory there given is due to Professor Runge and not to myself.

I am, gentlemen,

Yours truly,

H. KAYSER.

BONN, September 25, 1898.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in July and September. The annual subscription price for the United States, Canada, and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

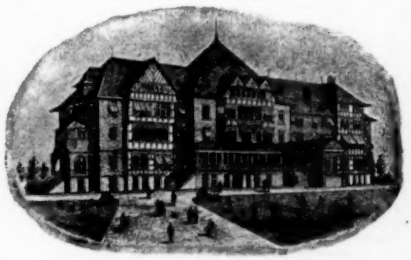
Wm. Wesley & Sons, 28 Essex St., Strand, London, are sole foreign agents, and to them all European subscriptions should be addressed.

All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

The Pennoyer

KENOSHA, WISCONSIN

On Lake Michigan
50 miles from Chicago



The Ideal Resting Place

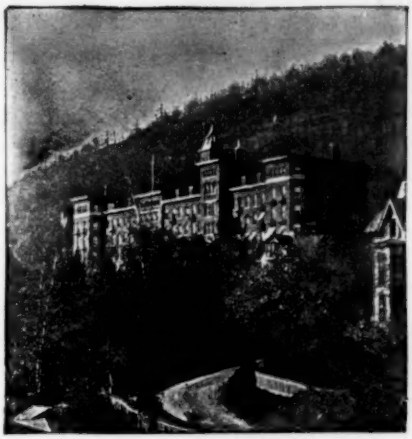
Established Forty Years

Combines in most perfect form the QUIET and Isolation of Country Life with the Luxuries of High-class Hotels, and the Safety of the best Medical Skill and Nursing

Elegantly illustrated descriptive pamphlet on application to

THE PENNOYER SANITARIUM CO.
KENOSHA, WISCONSIN.

HEALTH! REST! COMFORT



The Jackson Sanatorium

Dansville, Livingston County, N. Y.

Established in 1858. Most beautiful and commodious Fire Proof Building in the world used as a Health Institution. All forms of Hydro-therapeutics, massage, rest cure; electricity administered by skilled attendants. A staff of regular physicians of large experience; accommodations and service of highest class. Superior cuisine directed by Emma P. Ewing, teacher of cooking at Chautauqua. Do not fail to write for illustrated literature and terms if seeking **health or rest.** Address

J. Arthur Jackson, M.D., Secretary, Box 2003.

"A PERFECT FOOD—as Wholesome as it is Delicious."

Walter Baker & Co.'s Breakfast Cocoa.

TRADE-MARK.

THE STANDARD FOR PURITY AND EXCELLENCE....

Costs less than one cent a cup

Our Trade-Mark on Every Package.

Walter Baker & Co. Ltd.
DORCHESTER, MASS.
ESTABLISHED 1780.

THE SMITH PREMIER
THE MIGHTIEST WRITERS
are those who do the actual work in the vast correspondence of a nation. In this work one.....
SMITH PREMIER TYPEWRITER
is equal to scores of pens. The pen has given place to The Modern Writer, The Smith Premier, the machine typical of progress, the acknowledged leader in improvements.
SEND FOR CATALOGUE.
The Smith Premier Typewriter Co.,
SYRACUSE, N. Y., U. S. A.
THE MODERN WRITER

OUR PRICES SEEM STRANGE

"SUITS, $15.00 TO $50.00."

$15.00 SUITS

Mean staple materials, linings and trimmings bought in enormous quantities for our stores in all the principal cities, thoroughly organized workmanship, and a system eliminating every unnecessary expense without sacrificing quality.

$50.00 SUITS

Mean newest styles, exclusive weaves and latest vogue in trimmings. These cost more, but we buy them cheaper than most tailors. The most subtle skill in cutting and making is employed throughout, ***sparing no expense*** which will contribute in the slightest degree to a finished result.

Between these extremes we ***suit*** everybody.

Samples mailed ***free.***

Nicoll THE TAILOR

Cor. Adams and Clark Sts., CHICAGO.

Spruce Bark Bed Sheets and Comfortables

A Luxury for the Healthy
A Tonic for the Convalescent
A Remedy for the Sick

And Spruce Bark Bed Comfortables and Sheets are a positive necessity to Travelers and Tourists obliged to sleep in strange beds and berths in hotels and on boats.

Spruce Bark Bed Comfortables and Sheets are made of the tender inner bark of the Canadian Balsam Spruce Tree, stripped early in the spring when the sap is rising in the tree. By a special process the bark is made into thin sheets as smooth, soft and pliable as cloth and in which all the powerful aromatic and balsamic qualities of the spruce are permanently retained.

Nervousness, Insomnia, La Grippe and ordinary Colds are almost completely allayed with a single night's rest between Spruce Bark Bed Clothes and their constant use is recommended by Physicians as an absolute protection and preventive against these ailments.

The only difference between the Comfortables and Sheets is in weight. The Comfortables weigh about 1 lb., while the Sheets are specially selected light weight and weigh less than 12 oz.

Spruce Bark Bed Comfortables and Sheets, size 64x72 in., are packed in curious wooden bags, silk lined and trimmed with silk, and, if your dealers cannot supply them, we will ship anywhere in the U. S. or Canada, carriage and duty free, on receipt of price, $2 each, for either Comfortables or Sheets. Money refunded if not satisfied.

Booklet containing testimonials sent free on request.

The King-Jones Co., Department P. N., Toronto, Can.
Jones & Co., Department P. N., Niagara Falls, N. Y.

A PIANO

at a NOMINAL PRICE.

Chicago's largest music house, Lyon & Healy, to sharply reduce stock, offers sample new uprights, slightly used pianos, and second-hand instruments, at almost nominal prices. Good durable uprights as low as $100, warranted as represented. Square pianos $20 and upward. Grands from $200. Send for complete list. Among the makers are: Decker Bros., Hardman, Knabe, Steinway, Weber, Hale, Bauer, Fischer, Hazelton, and others. If you are interested in a piano, do not fail to write. Any piano not proving exactly as represented may be returned at their expense. Address

LYON & HEALY,
Wabash Ave. and Adams St., Chicago.

PAPER

In proportion as society refines, new books must ever become more necessary.
—Goldsmith.

As society refines, so also does it become more critical.

Lovers of Literature are Admirers of Art.

Papermaking is an art not learned in a day.

ESTABLISHED 1844.

J. W. BUTLER PAPER Co.
CHICAGO.

The Greatest Historical Work of the Century.

History for Ready Reference and Topical Reading.

In Five Imperial Volumes.

By J. N. LARNED,

Ex-Pres. American Library Ass'n.

This work is in itself a ***complete Historical Library.*** The fruit of the ripest scholarship has been gathered upon thousands of topics, from thousands of volumes.

A ***complete system*** is given to ***History,*** presenting its topics in their ***sequence*** and ***inter-relations,*** most convenient for reading, for study, or for reference.

The time ordinarily spent in seeking accurate historical information is, by this work, saved by the many years of laborious research and discriminating thought expended in its preparation. It makes one acquainted not only with ***History*** but with ***Historians.***

Nothing like it has ever been attempted, and, in the opinions of the most distinguished literary men of all professions, it is the ***greatest Historical Work of the Century.***

These opinions, with full information, sent on application. Sold only by subscription, and sent, carriage free, to responsible subscribers on easy payments.

. ***Experienced Solicitors Wanted.***

Address the Publishers,

The C. A. NICHOLS CO.,

Springfield, Mass. ***Chicago, Ills.***

The History for Ready Reference is an important work, representing both History and Literature. It furnishes a consensus of opinion of the best historians upon great historical questions and the reduction to a system of the great body of History as presented in thousands of volumes. The use of these volumes must prove an inspiration, whether in the family, in the study, in the office, or in the school.

WILLIAM R. HARPER, President,
Chicago University.

THE

Morgan Park Academy of The University of Chicago

A thorough Preparatory School for both sexes. Twelve Teachers, all specialists and college graduates. Eight buildings, Athletic Field, Gymnasium. Library of 4000 volumes. Delightful situation; near enough to the city for Chicago students to spend Saturday and Sunday home. Preparation for The University of Chicago and all other Colleges and Universities. Life in houses under Teachers' supervision. Introductory year for young pupils. For Calendar and full information address the Dean of the Academy, MORGAN PARK, ILL.

THE PHILOSOPHY OF THE HUMANITIES. By THOMAS FITZ-HUGH, Professor of Latin in the Univ. of Texas.

Une éloquente démonstration de la nécessité qu'il y a pour une nation, non pas à savoir, mais à avoir appris le latin.—*Le Temps.*

The work is scholarly and instructive and will be studied with interest and profit.—*Journal of Education,* Boston.

Brief, lucid, convincing, it must inevitably mark an era in scholastic practice all over this country.—*Alcalde,* Austin, Tex.

A sturdy advocate of the study of Latin.—*Pop. Sci. Monthly.*

63 pp. 50c. The University of Chicago Press, Chicago, Ill.

JUST PUBLISHED. PRICE TWELVE CENTS

The Natural History and Scientific Book Circular
Nos. 129, 130

MATHEMATICAL AND PHYSICAL SCIENCES

Including Works from the Libraries of
REV. A. FREEMAN, M.A., F.R.A.S., A. MARTH, F.R.A.S., and J. R. HIND, F.R.A.S., Late Superintendent of the Nautical Almanac Office, London.

Containing 3000 works (96 pages), including works on the Spectrum, Telescope, Eclipses, Comets, Meteors. To be had on application to

WILLIAM WESLEY & SON,

Agency of the Smithsonian Institution
U. S. Government Departments,

28 ESSEX STREET, STRAND, LONDON.

DOMINION LINE

MAIL STEAMSHIPS

WEEKLY SAILINGS

MONTREAL AND QUEBEC TO LIVERPOOL

FORTNIGHTLY SAILINGS

BOSTON TO LIVERPOOL

VIA QUEENSTOWN

Large, fast, twin-screw passenger steamers Superior accommodation for all classes of passengers. The St. Lawrence route to Europe is yearly becoming more popular—the three days of smooth-water sailing after leaving Montreal, before the Atlantic is reached, being much enjoyed.

The sea passage is a short one of 1656 miles.

Boston as a port of departure for Europe is very convenient.

For all information as to rates, etc., apply to any local agent of the company, or

GUS BROBERG, 69 Dearborn St., Chicago.

Richards, Mills & Co., 103 State St., Boston, Mass. **David Torrance & Co., Gen. Agents, Montreal**

GRAND TRUNK RAILWAY SYSTEM

Grand Trunk RY. SYSTEM,

THE FAVORITE ROUTE TO

All Canadian and Eastern Points

VIA THE "ST. CLAIR TUNNEL."

THROUGH SOLID VESTIBULED TRAIN SERVICE,

First- and Second-Class Coaches and Pullman Palace Sleeping Cars in connection with

THE LEHIGH VALLEY RAILROAD SYSTEM,

DAILY BETWEEN

CHICAGO and NEW YORK and PHILADELPHIA,

Via Niagara Falls and Buffalo.

Through Pullman Sleeping Car Service daily between Chicago, Detroit, Mt. Clemens, Saginaw Valley, Niagara Falls, Buffalo, Boston, Canadian and New England points via Montreal.

The Favorite Route for Summer Tourists, who should send their address to L. R. MORROW, Pass'r and Ticket Agent, Chicago, Ill., and ask for particulars regarding Summer Tours, Chicago to Niagara Falls, the Thousand Islands, the Adirondacks, the White Mountains, and the Summer Resorts of the Coast of Maine, which will be sent to all applicants free of charge. **Sale of Summer Tourist Tickets Commences June 1.**

For rates, Sleeping Car reservations, folders, etc., apply to

L. R. MORROW, CITY PASS'R & TKT. AGT.,
103 CLARK ST., CHICAGO, ILL.

8 BEAUTIFUL ETCHINGS

ILLUSTRATING AMERICAN SCENERY AND AMERICAN ACHIEVEMENT

ON

"AMERICA'S GREATEST RAILROAD"

An Illustrated Catalogue

Containing miniature reproductions will be sent free post paid on receipt of one 2 ct. stamp, by George H. Daniels, Gen'l. Pass'r. Agt. Grand Central Station, New York.

COPYRIGHT 1896, BY GEORGE H. DANIELS, GENERAL PASSENGER AGENT

NORTH & SOUTH

VIA THE

MONON ROUTE

R. R. Donnelley & Sons Co.

The Lakeside Press

PRINTERS AND BINDERS

THE PRINTING OF BOOKS DEMANDING TASTE AND CAREFUL EXECUTION, PRIVATE EDITIONS, COLLEGE CATALOGUES AND ANNUALS A SPECIALTY. WE PRINT MORE FINE BOOKS THAN ALL OTHER HOUSES WEST OF NEW YORK. OUR NEW FACTORY, RUN ENTIRELY BY ELECTRICITY, IS THE MOST ADVANCED PRINTING PLANT IN THE COUNTRY. THE LAKESIDE PRESS BLDG., PLYMOUTH PLACE, COR. POLK, CHICAGO.

Correspondence Instruction

The University of Chicago offers advantages for non-resident students through its Correspondence-study Department which cannot be surpassed. Degrees are not granted upon work done wholly by correspondence, but when the courses are completed at the University credit is given so that the time of required residence for the Bachelor and Doctor's degrees is materially shortened. The work offered includes courses in **Theology, Philosophy, History, Pedagogy, Sociology, the Languages, Literature, and Mathematics.**

Circulars giving detailed information may be had by addressing

THE CORRESPONDENCE-STUDY DEPARTMENT,
The University of Chicago, Chicago, Ill.

An Ideal Ocean Voyage

is fully realized on the luxuriously equipped

Compagnie Generale Transatlantique
FRENCH LINE

The culture and refinement of the entire world represented on every trip. Fast express steamer to Havre leaves New York every Saturday. Through vestibule train to Paris in 4 hours.

MAURICE W. KOZMINSKI,
Gen'l Western Agent, No. 71 Dearborn St., Chicago.

... TEACHERS ...

Union Teachers' Agencies

of America. Rev. L. D. BASS, D.D., Manager.

Pittsburg, Pa., Toronto, New Orleans, New York, Washington, D.C., San Francisco, Chicago, St. Louis, Denver.

There are thousands of positions to be filled soon. We had over 8000 vacancies last season. More vacancies than teachers.

Address all applications to PITTSBURG, PA.

THE WESTON STANDARD

VOLTMETERS & AMMETERS

Portable,

Accurate,

Reliable and

Sensitive.

WESTON ELECTRICAL INST. CO.,
114 WILLIAM ST., NEWARK, N. J.

Law

Chicago Law School

Preparatory Course. Undergraduate Course of three years leads to LL. B., and admission to bar. Post-Graduate Courses lead to Degrees of LL. M. and D. C. L. Fall term begins September 6. For Catalogue, address J. J. TOBIAS, Sec., 115 Dearborn St., CHICAGO, ILL.

MEDICAL STUDENTS

are best prepared for successful careers by a course combining actual practice with laboratory and clinical work. This and other advanced ideas are features of

HARVEY MEDICAL COLLEGE, CHICAGO.

Any interested in the study of medicine can obtain further information from

FRANCES DICKINSON, M. D., 167-171 Clark Street, Chicago.

SIMEON W. KING

Attorney at Law,

United States Commissioner

Commissioner of Deeds

For ALL the States and Territories.

Commissioner for U. S. Court of Claims at Washington, D. C.; **Government Passport Agent** at Chicago, Ill., and Notary Public. Acknowledgments, Affidavits and Depositions taken. Address all correspondence to or call at *510, 132 Clark Street,* Chicago, Ill.

Please mention the ASTROPHYSICAL JOURNAL when writing regarding advertisements in this magazine

Hand Book of Graduate Courses

SIXTH ANNUAL EDITION

Edited and published by the National Federation of Graduate Clubs . . . .

Contains:

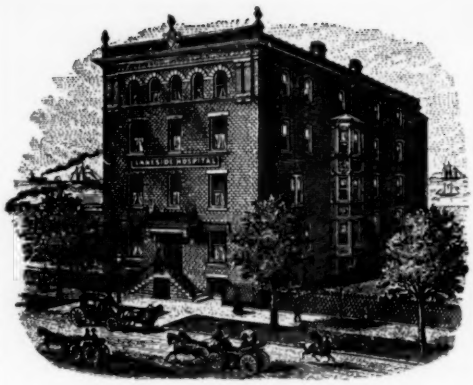
1) A Classified and Comparative Statement of the Graduate Courses offered by all the Graduate Schools and Colleges in the United States.
2) A Brief Description of the Different Universities.
3) A List of Instructors, with their degrees and positions held, arranged by institutions, and sub-classified by departments.
4) A List of Doctor's Theses in preparation.
5) A List of Candidates for Higher Degrees for the Previous Year, and the titles of their theses, also the positions secured.
6) The Proceedings of the last Convention of the Federation, with Address of Prof. James H. Tufts, of the University of Chicago.

This book should be in the hands of every student and educator.

220 closely printed pages. Price Fifty Cents.

GEORGE WYLLYS BENEDICT
(Harvard) Editor-in-Chief
FREDERICK A. CLEVELAND
(Univ. of Chicago) Business Manager

ADDRESS: BOX 183, FACULTY EXCHANGE,
THE UNIVERSITY OF CHICAGO, CHICAGO, ILL.



Lakeside Hospital

(Incorporated 1884)

4147 Lake Avenue, Chicago

Built expressly for the purpose after many years of hospital experience. Forty private rooms of the very first class. Equipped for the care of the sick in a manner not attainable in any home, private residence or hotel.

Non-contagious medical and surgical cases of all kinds admitted. Special provision has been made for obstetrical cases.

Nurses furnished to physicians or private families either in the city or country at any time.

Special Terms to University Students

Nelson H. Henderson, M. D.
Proprietor and Physician and Surgeon in charge, with associated staff.

Telephone Oakland 221

Globe Card Index File.

A SIMPLIFYING, systematic card arrangement of necessary information—anything—on any subject. You can pick out a desired address, name, quotation, account, cost, stock record, in a moment. A perfect index to anything you will ever need a second time.

Globe Goods are Good Goods

Send for a catalogue—illustrated—of the Globe Card Index File and Globe Business Furniture. . . . .

THE GLOBE COMPANY,

226-228 Wabash Ave., CHICAGO. **1224-1248 W. Eighth St., CINCINNATI.** **Fulton & Pearl Sts., NEW YORK.**

Chicago Office: 144 MADISON STREET

"PURE WATER Does Not Exist In Nature."

A radical statement, but authentic. To maintain normal conditions in the human body, there is absolutely required over three and one-half pounds of water daily, and less than two and one-half pounds of solid food. Water is found in every tissue and part of the body without exception. If it is *not pure* it defeats the purpose for which it is used. Absolutely pure water devoid of germs or inorganic salts is procured only through the process of distillation and

The Sanitary Still

Preeminently Leads!

Philippine Expedition Fully Equipped.
Only Still Recognized by U. S. Government.
Twelve Styles from which to Choose.
Double Capacity—Same Price.

The Sanitary Still fits on any wood, coal or gas stove. Simple as a tea kettle, easily cleaned, lasts a lifetime, produces pure, sparkling water at a cost of one to two cents a gallon.

Write for booklets containing letters from prominent bankers, physicians and pastors from every State in the Union and several foreign countries.

THE CUPRIGRAPH CO.,

109 North Green Street CHICAGO, ILL.

ALLAN LINE.

Royal Mail Steamship Co.

ESTABLISHED IN 1854.

The Company's Fleet consists of Thirty-four Steamers aggregating 134,937 tons.

Tunisian, 10,000 tons—building. Bavarian, 10,000 tons—building. Castilian, 8,800 tons—building.

Steamers sail weekly from Montreal to Liverpool during the season of navigation; also separate service from New York to Glasgow.

The St. Lawrence route is 1000 miles less ocean sailing than from New York.

Three days' sailing on smooth water.

The steamers are fitted with every improvement for the comfort of the passengers, in all classes, including bilge keels, making the vessels steady in all weather, electric light, midship saloons, spacious promenade decks, music rooms, smoking rooms, etc.

Special attention has been paid to the ventilation and sanitary arrangements. An experienced surgeon is carried on all passenger steamers.

Rates of passage lower than by most first-class lines. Circular giving rates and sailings, on application to

ALLAN & CO.,
174 Jackson St., Chicago; or,

H. & A. ALLAN, Montreal.

Preliminary Table of Solar Spectrum Wave-Lengths

By Henry A. Rowland

PROFESSOR ROWLAND'S important TABLE OF SOLAR SPECTRUM WAVE-LENGTHS, which has been generally adopted by spectroscopists as the standard of reference, was first published in the *Astrophysical Journal*, beginning with Vol. I, No. 1, January 1895, and continuing to Vol. V, No. 3, March 1897. The Table gives the wave-lengths of nearly 20,000 lines, measured from photographs of the solar spectrum made with the concave grating at the Johns Hopkins University. *** The eighteen separate parts, together with a table of corrections and additions, have been reprinted in a single volume of 225 pages, copies of which are now offered for sale at $1.50 each.

ALL ORDERS SHOULD BE ADDRESSED TO

The Press Division
The University of Chicago
Chicago, Ill.

BINNER ENGRAVING CO.

FISHER BUILDING
CHICAGO

PHOTOGRAPHIC and Lantern Slide Apparatus and Materials for the Scientist and Amateur

Anthony's Micrographic Camera

Anthony's Lantern Slide Camera

A. T. Thompson & Co's Improved Electric and Lime Light Stereopticons

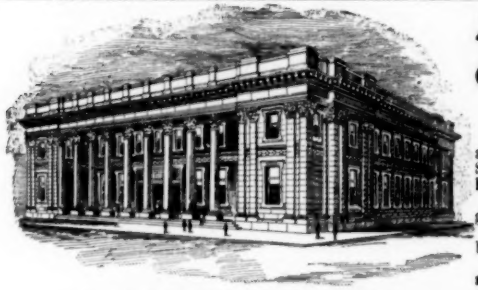
Hand Cameras and Outfits of all kinds.

Tripod Cameras, Lenses, Shutters, New American Films, Dry Plates, Developers, Chemicals, Flash-light Apparatus, American Aristotype and American Gelatine Papers, and everything requisite for either Amateur or Professional.

Books of Instruction

for the beginner or advanced worker.
Send for Booklets or Catalogue.

E. & H. T. ANTHONY & CO.
591 Broadway, New York
45, 47, 49 E. Randolph St., Chicago



Located in the New Building of the
ILLINOIS TRUST & SAVINGS BANK,
Corner Jackson and La Salle Sts.,
CHICAGO.

Safe Storage of Documents

AND OTHER VALUABLE PROPERTY.

Use of faultless material, most perfect devices and advanced methods of construction make the Safety Deposit Vaults of **The Illinois Trust Safety Deposit Co.** the most secure in this country.

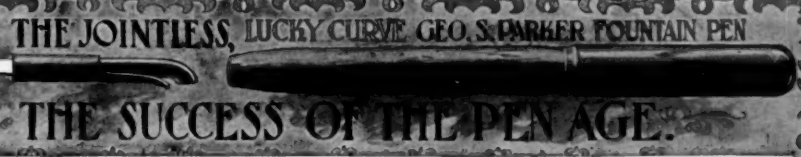
With greatest security are most spacious and elegant appointments for the convenience of patrons.

These mark the highest achievement in the building of safety deposit vaults.

All are invited to inspect them. No obligation need be felt to transact any business. We will feel amply repaid for the showing by the favorable comments that will follow an examination.

Popular prices prevail.

ROBERT BOYD,
Secretary and Manager.



THE SUCCESS OF THE PEN AGE.

The greatest improvement ever made in fountain pen construction.

NO SCREW TO BREAK. NO NOZZLE TO GET "STUCK." NO JOINT TO LEAK. PERFECTION.

To those who have never owned a Fountain Pen, the "PARKER" is a DELIGHT—to those who have tried others it is PERFECTION. First right in principle, then skillfully made to avoid the weak points found in other makes, Parker Pens seem to "go alone," so smooth and easy is the movement.

For sale by bright dealers everywhere. If the dealer of whom you inquire does not keep the "PARKER," and tries to sell you a "just as good," he is either honest in his ignorance, or trying to deceive you. If he will not supply you, we will. *Interesting Booklet Free.*

The PARKER PEN COMPANY, 34 Mill St., Janesville, Wis.
The largest bona fide manufacturers of Fountain Pens in the world.

SECTIONAL VIEW.

ALVAN CLARK & SONS

CAMBRIDGEPORT, MASS.

Manufacturers of

ASTRONOMICAL TELESCOPES

With Improved Equatorial Mountings

Sizes from Four-inch Aperture
to the Largest Ever Ordered

Send for Photographs of our Portable Equatorials or five and six-inch fixed, with accessories — the best to be had for educational and amateur work.

Terrestrial Telescopes for private residences

The performance of our instruments, famous the world over, is their own greatest recommendation. An experience of nearly a half century in the art of telescope making enables us to apply a degree of skill and judgment to our work which make our objectives **unrivalled in excellence.**

Among our telescopes are

The Lick Refractor, 36-inch.
Pulkowa Refractor, 30-inch.
Washington Refractor, 26-inch.
University of Virginia, 26-inch.
Princeton Refractor, 23-inch.
Denver Refractor, 20-inch.
Chicago Refractor, 18.5-inch.
Rochester Refractor, 16-inch.